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THE SCIENTIFIC MONTHLY

DECEMBER, 1928

VISUAL ILLUSIONS OF MOTION

By Professor WALTER R. MILES

STANFORD UNIVERSITY

I. The Bystander's Illusions of Motion

We were standing on the lawn in front of the Stanford Quad when my friend said, "Did you notice that sprinkler a minute ago? It was turning toward the right but it stopped and then started turning in the opposite direction. Some of them are made that way. I suppose the inventor thought that his device would throw the water on both sides of the plants." This illusion of motion, seeming to turn first one way and then the other, well known to the psychologist, is more often called the "windmill illusion" for the simple reason that windmills are older than lawn sprinklers and that their twirling blades are frequently observed from the distance most suitable for the appearance of the illusion. Sellers of windmills know about this oddity of perceived motion. Not infrequently it causes them prolonged discussions with some irate customer who stoutly contends that there is a defect in the mill because it revolves now in one direction and again in the opposite one. Windmills, electric fans and lawn sprinklers with revolving arms are alike in resembling a wheel with prominent spokes and an insignificant rim. They are quite open and when viewed nearly edgewise and at some distance it is difficult to tell positively which parts are in the foreground and which in the background. If foreground is actually seen as foreground the motion will be in one direction, but if background is for the time seen as foreground the apparent motion will be in the opposite direction. The illusion, therefore, belongs to the "reversible perspective" class, being a case of confusing front with back as illustrated by the diagram (Fig. 1). If

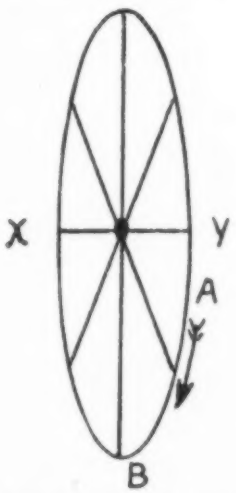


Fig. 1. If Y and the arrow appear to be at the front of the figure then this section is moving downward, but if X is seen as foreground then the front is moving upward. The figure may also be seen as without perspective. Similarly a lawn sprinkler may at times be seen to expand and contract rather than to revolve.

at first glance this wheel appears to be facing toward the reader's left hand then the foreground is represented as moving downward, but if the wheel is facing the right then the foreground is moving upward. The wheel may of course be seen by the same person in either of these two ways. The shift can to some extent be controlled by fixing the eyes first on one part and then on another (x and then y). This is an illusion of motion, but is one that occurs independently of the observer's position: he may be stationary or moving, whether by his own locomotion or carried by some vehicle.

Seeing Movement in the Motionless

The familiar circumstances just considered were those where an *actual motion was reversed*, that is, it was misinterpreted as to direction. Because we have a clear impression that motion is or has to be one way or the other this has been called an illusion of motion. There are of course many instances where the amount or rate of motion are not rightly perceived, but here since there is no natural dichotomy, it is common to speak of "errors of judgment," some of which may be overcome by training and experience.

Now we come to another accepted illusion in the class of natural events of which the waterfall is an example. When an observer, in this case preferably stationary, steadily watches the moving column of water he has presently a definite impression that the adjoining banks of rock and earth and the projecting boulders and tree trunks forming islands within the fall are all moving in a direction opposite to that of the water. Here he does not misinterpret the direction of the actual motion that exists but rather *creates an opposed motion* for the stationary areas that border or are inclosed in the field of real motion. This illusion is present and sometimes awkwardly so when we try to cross a stream on a foot log. We get the same effect when slowly moving reading material appears on a motion-picture screen, and in the apparent motion given to the moon and to objects on the horizon when clouds are moving rapidly across the sky. This illusion is not conspicuous as we view a moving train on a distant landscape, but if we are standing near the edge of a platform as a long train passes we should exercise care: a motion illusion of great hazard may confuse us, one that has doubtless been the real reason for many a person's falling under the train.

The "waterfall illusion" evidently depends on the objective condition of movement of relatively large areas of the visual field. This type of visual experience does not depend upon confusion between foreground and background. It rests rather on the tendency for the visual field to operate as a compensating system balancing its parts one with reference to the other. This tendency for the visual field to behave as a realm of compensating motions, some real, others induced, is especially noteworthy when the observer is being carried along in a train, automobile or airplane. We will presently return to a consideration of it under these conditions.

The Puzzling After-Effect of Movement

One point more on the waterfall illusion concerns the after-image of movement as it relates to industrial operations. Advertisers now and again for window attraction make use of a disc on which a black spiral is traced, the disc being made to revolve slowly. If a person looks steadily at the center for a few moments and then glances at some stationary object he sees a curious swelling or shrinking (according to which way the spiral has been revolving) in whatever is looked at. The impression is inescapable; it is the after-image or after-effect of the movement. If a mechanic

has in his field of view and is watching continuously and closely a rather slowly moving area, rotary or linear, which he is adjusting to some other surface or point, on stopping the motion of approximation he will have the distinct impression that the thing is backing away or that the motion is reversed; he must beware of trying to compensate for this at the moment. This is not a defect of the machine or an eye trouble. It is a normal phenomenon of vision. If it is bothersome it can be reduced by arresting the motion before the final contact is made, thus allowing the after-effect to die away.

The Dark Spook and His Speed

The "picket-fence illusion" represents a third group of visual experiences in which apparent *speed of movement is accentuated.* It is not dependent on peculiarities of the eye but is normal and objective. On looking through one picket fence at another farther away one sees alternate "dark" and "open" spaces themselves much wider than the individual pickets or openings in the fences. According to the distance that the fences are apart and the position of the observer these dark phantoms are broad or narrow. The same phenomenon may be produced by window screen and lace curtain. It is directly made use of in a visual acuity test object manufactured by Bausch and Lomb. In this case ruled glass gratings, the scratches filled with opaque material, are superimposed. One plate is rotated on the other about an axis perpendicular to their surfaces and dark bands appear. See Figure 2. The width of these is determined by the degree of rotation. The phantom is stationary if the screens and the observer keep constant position with reference to each other. A slight movement of either screen or observer produces a large and unexpectedly rapid movement of the phantom.

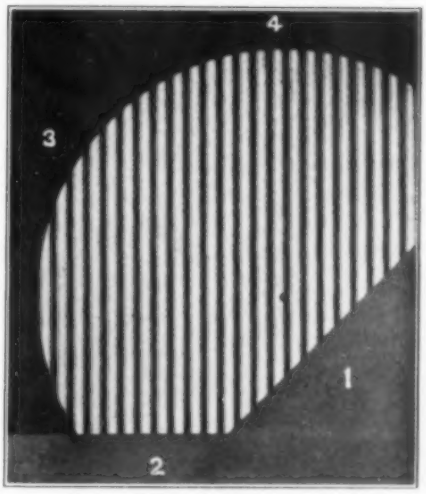


FIG. 2. DARK BANDS MADE BY SUPERIMPOSING TWO GLASS GRATINGS RULED 200 LINES TO THE INCH. THE SCRATCHES ARE FILLED WITH OPAQUE. ROTATION OF ONE GRATING ON THE OTHER MAKES THE BANDS WHICH APPEAR IN THE ILLUSTRATION. THE EFFECT AT THE INTERSECTION OF THESE BANDS WITH THE BORDER DIFFERS ACCORDING TO THE ANGLE AS SHOWN AT THE POINTS NUMBERED ON THE ILLUSTRATION. A SIMILAR EFFECT OF BANDS COMES FROM LOOKING THROUGH TWO PICKET FENCES OR TWO SCREENS.

The Movies Just Appear to Move

Finally, for the stationary observer we may mention the "firelight illusion" of motion. Sitting near an open fire that is flickering rather than vigorously blazing one notices that the andirons, crane or other objects appear to execute rapid shifts in position changes sometimes lateral and sometimes vertical. This is due to the fact that the objects are illuminated from one position and then another as the fire blazes up, now here and now there. The highlights and shadows change for the objects and for the general background. In place of seeing the object first this way then that way a kind of fusion takes place in vision which bridges the gap and the object seems actually to move from one position to another, back and forth. One

of my colleagues, a physicist, once called my attention to an experimental set-up which included wiring between lamps well spaced, that illuminated alternately. Under these conditions some of the wiring not in immediate contact with the baseboard seemed to move forward and backward as does a conductor in a strong electrical field. To convince one's self that the wires were not moving one needed to actually touch them while the lights changed. In this situation *we create what appears as primary motion* in really static objects by giving successive views a meaning of motion. Ordinarily an object which occupies first one position and then another has to move across the distance that separates the two points. This is in general so fundamental that it tends to become the basis for all our interpretations. The principle plays a prominent part in the effectiveness of electric flash signs, it is basal in motion pictures and probably at root is related to the condition that our vision is not really continuous. The "firelight illusion" is as old as the name I have given it implies, but recent psychological discussion has made much of it under the term "phi-phenomenon" and it is prominent in the new Gestalt psychology.

II. The Train Traveler's Illusions of Motion

Under the conditions present when I am being rapidly moved by train, automobile or airplane nearly everything which makes up my visual field is a moving image. The situation is just the opposite when I stand leaning against the fence looking into the Grand Canyon. Sitting on the observation platform while the train moves along at forty-five miles an hour the visual field has to be constructed in a totally different manner, and to describe it in most general terms, everything is turned into the "waterfall effect." The railroad ties and the crushed rock of the road bed, the cinders and the grass on either side of the road make up a softly merging band of gray, brown and perhaps green. If I fix my eyes about a hundred feet down the track I see nothing near at hand in detail except the clear-cut steel rails which appear to flow rapidly into closer approximation with each other. The clouds and sky in the upper part of my visual field in place of flowing from me

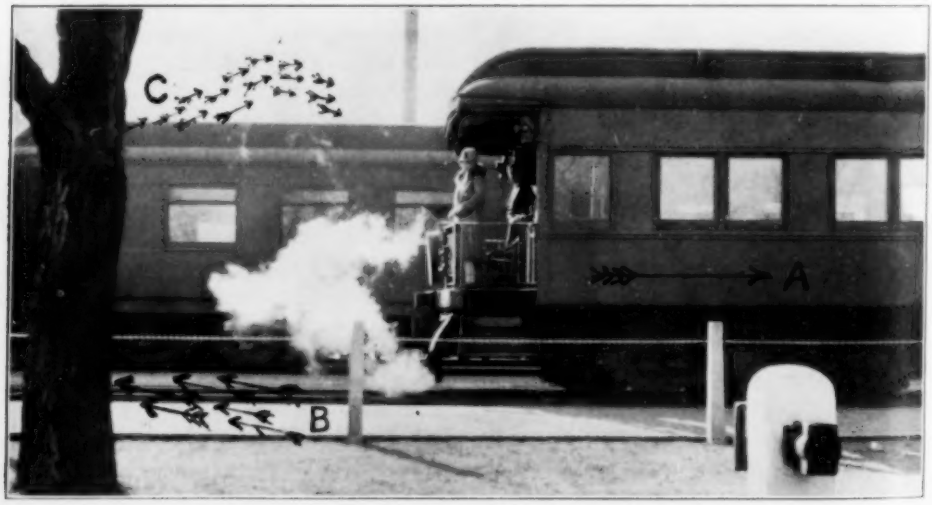


Fig. 3. Illusion of motion when riding on the observation platform. A, direction of the train's motion; B, motion in the lower part of the visual field; C, illusion of motion in the upper portion of the field of view.

appear to rise rapidly above the horizon as if a storm were approaching and were gaining on the train. See Figure 3. This is our old "waterfall illusion" in a new form. As I am being rapidly moved forward, the immediate territory serves as a fixation field, and as it sweeps rapidly away the opposite motion is induced in that part of the visual field that is going away from me relatively more slowly. We have already mentioned the compensating features of the visual field. White objects in the field of view cause other portions of the field to appear darker. Prominent colored objects or patches of color cause shadow fields of the complementary color to be induced in adjoining areas. Portions of the field seen in clear detail appear to be nearer to us than vague or dim portions. The vague parts seem, in fact, to recede, thus emphasizing a depth factor which, in general, applies to the whole visual field and differentiates foreground and background. The lower part of the visual field is interpreted in general as near at hand and in contrast to this the upper part receives the interpretation of distance. Now we see again evidence that the visual field operates as a compensating system maintaining an equilibrium in terms of its own content, for as noted above the introduction of large predominating areas of motion within the visual field induces the appearance of opposite motion in the adjoining large areas. Just as the induced contrasting color appears to be unsaturated, diffused and without sharp boundaries or strong body so the induced motion is in general less conspicuous than the moving areas which induce it.

If the sky is cloudless and without discernable details the traveler may scarcely be aware of the induced movement in the upper part of his visual field. Yet the illusion may show itself in the apparent bending over of a tall tree or flagpole in such an environment

FIG. 4. THE TALL TREE, THE TELEGRAPH POLES AND THE FLAG POLE IN THE DISTANCE ARE APPARENTLY SWAYED FORWARD BY THE ILLUSION OF MOTION INDUCED FROM THE RAPIDLY RECEDING FOREGROUND.

as that shown in Figure 4. However, if the train stops and the moving stimulus is suddenly withdrawn there is a prominent after-effect of motion, which is similar to what he would experience if he found himself suddenly transported to the front end of the same train in motion. The platform and road-bed seem to be rushing toward him. This is, of course, the ordinary experience when riding in an automobile, where the objects approached are faced rather than receded from. If under these circumstances one looks steadfastly a long distance down the road and at the same time pays attention to the objects near at hand which are being immediately approached, the latter appear to swell rap-

idly in size. The sky and clouds recede as if driven by a rapid wind in the direction of one's travel, the distant mountains seem to sink down and in general the landscape appears somewhat flattened. Whether the landscape is receding and the upper portion seems to come forward or is being approached when the upper part seems to recede, that is, whether the traveler is facing backward or forward there is an axis about which the two halves of the visual field appear to revolve. This axis is not very definite. I can easily make it the far horizon if I fixate that locality, or if I fixate a position considerably nearer, it seems in general to be there, but I can not under any circumstances bring it nearer than several hundred feet from the train.

The Illusion of Shrinking and Sinking

As my journey proceeds objects are rushing into my visual field from both sides. When they come in they are large, but owing to the rapidity of my motion in a short time they have astonishingly decreased in size. The train passes over a bridge with steel superstructures. As we leave it (see Fig. 5) the structure looks large and occupies a considerable portion of my visual field. Less than sixty seconds later (see Fig. 4) the same bridge appears only faintly at the point where the tracks seem to converge, having shrunk to less than one one-thousandth of the previous visual area. As the bridge recedes during these few seconds it has seemed actually to sink into the ground or to shrink like a punctured balloon.

Watching the telegraph poles as they rush in and recede, we try to account for their rapidly changing size: they seem to sink into the ground or to telescope on themselves. If linemen are working on the poles so rapidly passed one can not be sure whether a given man is holding his position steadily or climbing down or up the pole. Observing men adjusting the lights on the derail switches I have noticed that one frequently gets the impression that the man is climbing down from the light whereas this effect is simply the result of the rapidly decreasing size of the whole field of vision, in other words the lowering or shrinking of the object in question.

FIG. 5. A BRIDGE JUST PASSED OCCUPIES A LARGE PORTION OF THE FIELD OF VIEW AND ONE MINUTE LATER, AS IN FIGURE 4, IS REDUCED TO 1/1000 OF THE FORMER APPARENT AREA.

The Illusion of Twisting and Revolving

A third and very striking illusion which is to be noted from the observation platform is "twisting." Here the telegraph poles serve us best as objects of demonstration. When we pass the poles the cross beams to which the wires are attached are at right angles to the rails. At the instant of passing we can see only the ends of the cross beams, but about five seconds later we are looking at their sides (see Fig. 6), that is, the telegraph pole has taken on the aspect of a cross. The change in point of view is

FIG. 6. THE ILLUSION OF TWISTING MAY BE SEEN EASILY FROM INTENTLY WATCHING TELEGRAPH POLES AS WE ARE SWEPT RAPIDLY PAST THEM.

so rapid that if one fixates the pole, trying to keep his eyes definitely on it as it "travels past," one has the impression that it twists in the ground, executing about an 80° turn. Here the motion is imputed to the object itself to account for the change in point of view, and therefore one gets the impression that the pole revolves on its own axis at first very rapidly and then in a negatively accelerated fashion. The poles at one's right revolve clockwise, those at the left counter-clockwise, in each case appearing to execute almost a quarter turn.

This revolving of objects is always a conspicuous illusion of the visual field as one sits in the coach, looking out from the side of the train. A house standing near the track if observed in this manner seems indeed to turn through an angle greater than ninety degrees. As one faces the window and turns his eyes far to one side so as to pick up the image of the house when it comes in view and then follows it with a pursuit movement of the eyes until it goes out of view he gets this revolving illusion most distinctly. The same illusion is conspicuous with reference to a fence that runs off at right angles to the railroad track. If one fixates a point on the fence say three hundred feet from the track, before passing the end of the fence, the entire line of posts and rails will seem to revolve as around an axis located at the point of visual fixation.

The "Waterfall Illusion" Seen Sidewise

We thus see that the revolving illusion is closely associated with the general illusion present in the field of view as noted from the side of the train. In place of having the motion in the direction to and from the observer in the direction of travel it is now lateral to him. The lower part of the visual field rushes backward as he faces forward, while the upper part of the field is in general apparently moving forward in the same direction as the train. Observing the clouds one has the impression that the wind is blowing them in the direction that the train is traveling. The imputed motion is not limited to the sky and clouds but tends to include all of the landscape beyond the actual point of visual fixation. It is an approximate law of vision that an object which is seen clearly and constantly appears at rest, as compared to the remainder of the field. This statement is easily confirmed by the experience of passing through a wooded region. If as I pass, whether walking or riding, I fixate a tree a hundred feet away at the side, all the trees nearer will appear to pass me in one direction while all those farther than the fixated tree pass in the other direction. If I walk through the woods under a bright moon the moon will seem to be going in the same direction as I. There is nothing beyond the moon that I can fixate and I can not therefore get the moon included on the near side of

the axis about which my visual field seems to divide or revolve.

On Riding Backwards and Forwards

In place of looking out of the window suppose I sit at the read end of the coach and look steadfastly at the front end, giving attention, however, to the peripheral field with the movements rushing by on both sides outside the car windows. Presently I become aware that the front end of the coach seems to be retreating, the coach appearing to grow longer. This is a compensation in the central part of my visual field for what is happening of the opposite tendency on the sides. This does not annoy me because the lengthening of the coach or the receding of the front of the coach from me is taking place in the direction that I think myself to be traveling. If I now change my position to one at the front end of the coach and, facing backwards, fixate on the rear end I see the landscape on either side rushing back and away from me as it does when I am on the observation platform. The end of the coach and all that makes up the lower, central and upper portion of my visual field has induced in it the opposite tendency, that is, it seems to be coming toward me. Probably this is one of the chief reasons for the discomfort that many people experience in riding backwards. Nervous people may get the impression that the car is crowding in on them.

Reading on the Train

We do not like to read with an unshaded lamp quite close at hand, because of the distracting streaks in the field of vision as the eye goes through its series of glances and pauses across the page. The visual field outside the limits of the book page or paper tends to claim our attention and if it contains an object of striking contrast such as the bright globe of the lamp, reading is made more difficult and more fatiguing. Similarly the train traveler should avoid holding his reading material in such a way that any considerable portion of the visual field is played upon by the moving landscape. If the visual field has much movement occurring across it, then that portion occupied by the book or paper will give the impression of movement in the opposite direction. This impression must be contended against and in a way compensated for by visual fixation and eye movements and therefore constitutes a definite handicap and a fatigue hazard. The visual field should so far as possible be limited to objects that are traveling with the reader. The common extended newspaper, tending as it does to take up nearly the whole visual field, has natural advantages for train reading.

Which Train has Started?

When our train is standing in the station with a train on each side we are often confused at the moment of starting, not knowing certainly whether they or we are pulling out. Ordinarily I impute the motion to myself and think that my train has started very slowly and without jerks. In this illusion of self-motion I follow what seems to be a deep-grained human habit, perhaps a fundamental one, for ordinarily in most familiar situations I am the object that moves with reference to a generally stationary landscape. Therefore, when nearly the whole visual field moves silently and evenly to one side it is very like the experiences when I move my head or when I walk, and thus I can quite easily convince myself that I am in motion. This is particularly true if the rate is within my walking or perhaps running speed. Then I seem as a rule to be the mover unless I find my experience wholly lacking in those cues

of auditory and tactual nature which would refer to the jostle of the train and to its rumble. If these are entirely absent I may suddenly correct myself. This mental measure which I have with reference to movement produced by my own locomotion pertains to the clearness with which I see things as I pass them. It plays a deciding rôle in causing the impression of "*myself moving past*" or at other times with higher speeds of "*having the landscape move past me.*" These impressions may be designated as the *pedestrian or slow vehicle experience* as against the *panorama experience.*

When a freight train is traveling slowly side by side with my passenger train and in the same direction, I look at the freight and feel we are traveling indeed very slowly. I appreciate only a relative difference in speed between the two trains whereas when I look at an open landscape on the other side of the coach I instantly adjust myself to the impression of rapid travel. The sense of movement is thus nothing trustworthy in itself except as it is based on trustworthy visual or tactual experience. No resident on the earth has the clear direct impression of rapid transit through space. The aviator if he sticks his head down in the cockpit has little more sense of traveling through space, in fact he has rather less, than a child seated on a rocking horse.

The Illusion of Sharp Vision During Motion

When we are in rapid transit we see best those things which are in line with our direction of travel. Thus from the side of the car we see "clearly" telegraph wires, fences and roads paralleling the track. The road is a particularly interesting thing to watch as I hold my visual position with reference to the frame of the window. The light cement road looks like a soft feathery path with two light-brown bands running through it (oil drippings from the two lines of traffic). The black streak of asphalt which divides the road in the middle appears indeed very black and sharp, but the equally black asphalt bands with which cracks in the cement have been patched or different sections of the road have been joined fade out entirely. I see these cross marks only if I jerk my eyes back and forth. I look at the telegraph wires: they seem to glide through my visual grasp almost as if between my fingers. They rise and fall slowly and evenly as the swell of waves. There is a moment of flutter when the telegraph pole goes by and a little unevenness when the splices "go through," but otherwise I have the impression of seeing the lines with great clearness and detail which I know to be entirely an illusion.

Two Visual Devils

During train travel many of the objects remain in view for a long enough time to satisfy the observer. However, there are some momentary visual experiences that may be cited. One annoying thing in all train travel arises from the fact that it is difficult to see the name of the town on the railroad station. The station for obvious reasons is near the track, and if your portion of the train stops far from the station or the train passes through without stopping observers from the side of the coach may fail to make out the name. There would seem to be a good opportunity in most towns and cities for "town-name-ads" well placed about two hundred or three hundred feet from the track, one on either side, that may be read when going or coming. In the matter of town name and local information, auto travelers now have the advantage.

In contrast to this rather negative momentary visual experience there is a

positive one that is of a very troublesome nature, and it is not an illusion! This arises especially from tall trees planted at the side of the right-of-way, in such a position that they cast their shadows across the track. A row of such trees, beautiful as they may be, produces an exceedingly irritating and painful flicker for thousands of travelers who are trying to write or read when the train passes that spot. If such rows of trees could be planted far enough back from the right-of-way so that their shadows would not fall upon the passing train the effect on the landscape would be equally pleasing and all the non-blind passengers traveling over that line would be grateful—if they thought about it. Transportation companies surely owe it to their patrons to guard them against this tormenting devil.

Grabbing an Eyefull

When we pass a freight train on the siding or perhaps moving in the opposite direction we are at times annoyed because our field of view has thus been cut off. However, the persistent observer can grab almost an eyefull of fairly non-illusion material from the momentary glimpses which are available to him through the openings between cars. Freight cars are in general about forty feet long and the opening between them is approximately four feet, so that when we pass a freight train it is cutting off the field of view about nine tenths of the time. The duration of view or glimpse that we get lasts from one twenty-fifth to one fifth of a second according to the speed of the train. We know from a great deal of laboratory experience with exposure devices that if one is looking at the right place and is ready for the exposure a brief uncovering of the object really serves the purpose for quite a comprehensive view. In Figure 7 one sees through the gap an engineer standing by his cab, and the numbers on the cab are legible. For such glimpses much depends on how near we are to the open-

FIG. 7. THE FREIGHT CAR EXPOSURE DEVICE WHICH PERMITS US A GLIMPSE FOR ABOUT ONE TENTH SECOND. WE MAY SEE CONSIDERABLE IF ATTENTION IS RIGHT.

ing and what is to be seen. There is no point in just mildly giving up in the presence of a clumsy freight train. What we see is like a succession of lantern slides. This glimpsing of things through the big exposure device of a freight train tells us a very important story. In a nutshell it is that vision is quick and comprehensive and that in general we look for a longer time than is necessary. We can economize vision and save ourselves visual fatigue by looking for shorter periods and with greater attention.

Movement and Experience

Some form of travel by rapid transit is now a characteristic feature of man's life. He does not travel with his eyes shut. If he looks at the region through which he passes his retinal fields must in general be fields of motion. We find that this condition brings about definite visual distortions or illusions. These are so pronounced in some cases as to make it impossible for him to be certain in his judgment. They show that the make-up of the visual field at any moment results from relative visual impressions or relations between these impressions. A visual field is a compensating system of experiences, one experience interpreting the other. What at one moment seems in motion may at another moment seem at rest. If a large part of the visual field actually moves in one direction other parts of it will appear to move in the opposite direction. In this complex known as visual experience we have a picture representing the whole range of dependent relationships which constitute man's environment and the very texture of his existence. Up and down, north and south, dark and light, movement and stationariness, all of these things have to be taken in pairs. There apparently are no fixed and independent points belonging in these systems, and to imagine that such stationary parts exist is simply to be caught in what is the greatest illusion of the time-space-being picture.

GEOGRAPHY OF A PORTION OF THE SAN LUIS VALLEY

By Professor RALPH H. BROWN
UNIVERSITY OF COLORADO

THE cultural landscape of the Monte Vista region, in common with that of all the irrigated portions of the western part of the San Luis Valley of Colorado, has resulted from the shaping of a rural life essentially middle western in its salient features to fit the stubborn demands of a remote, high-altitude, arid, intermontane valley to which, at a time seemingly longer ago than it really is, a Spanish-Mexican life had been incompletely adjusted.

DESCRIPTION

A Modified Middle Western Cultural Landscape

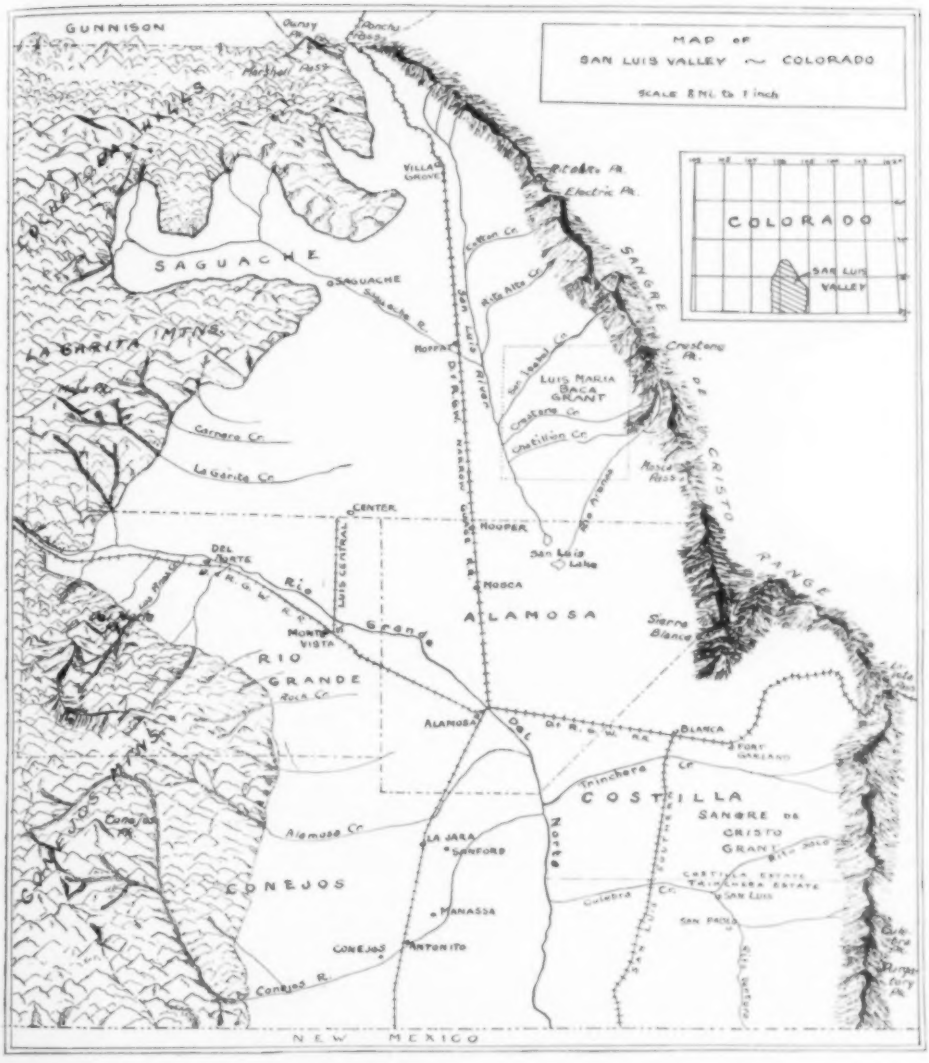
In the rural districts of the Monte Vista region, the homes are spaced at about one-half-mile intervals along the straight section-line roads which criss-cross without natural hindrance the monotonous surface of the compound alluvial fan of the Rio Grande del Norte. These homes and their surrounding barns and sheds—minus windmills and silos—possess not only the atmosphere of practical efficiency, but also the actual conveniences and luxuries, of their corn-belt prototypes.

A further modification of the local architecture and one suggesting also the delicate way in which an autochthonic culture has been fashioned to meet the practical needs of a more advanced society, is the ubiquitous potato cellar. Constructed in the main of thick walls made of local adobe dried in the sun, and covered with sod roofs, they are strongly reminiscent of the picturesque Mexican house. Moreover, the three-foot-thick walls are found to be a careful adjustment to the absolute minimum winter temperature of −30 degrees F., in the adequate protection provided to stored potatoes, the great cash crop of this locality.

The Mexican adobe dwellings of the indigenous culture are now to be found only occasionally in the rural districts and practically never in the highly prosperous parts thereof. Commonly these older one-story houses are clustered about the outskirts of towns and villages as, for example, in the Lariat section of the town of Monte Vista. The latter, of three thousand population, quite typical of the communities spaced at about twenty-mile intervals across the

(Photo by Eben Fine, Boulder)

A VIEW OF CHAMA IN THE EASTERN PART OF THE SAN LUIS VALLEY.



broad, flat floor of the central section of the valley, is given over to trading in the produce, entirely agricultural, of the surrounding irrigated country, of necessity seeking a market in regions of denser population. Almost replicas of small towns in the middle west except for the Artesian wells and the gurgling irrigation ditches which thread the streets, they seem curiously misfit in the spectacular natural setting provided by the foothills of the San Juans only a dozen miles to the west, and about forty miles to the east by the inspiring majesty of the Sangre de Cristo Range, which culminates in the massif called Sierra Blanca.

Evidences of Recent Change

Evidences of successive stages in the settlement of the valley are also unmistakably recorded in the landscape. The older farmhouses, bearing many evidences of pioneer days, are notably close

(Photo by Eben Fine, Boulder)

THE ADOBE HOUSE IS STILL TO BE SEEN IN PARTS OF THE MONTE VISTA REGION.

to the Rio Grande or to the smaller streams which debouch from the mountains upon the plain and are lost in it as they flow across the sandy surface. The newer and more modern homes, on the other hand, are obviously concentrated in the higher parts of the fan, across which great open trenches carry water to points twenty-five to thirty miles north and south of the Rio Grande. These main ditches, like the roads, stretch for miles without a turn, and from them water is deployed in minor canals throughout their lengths.

Indicative of changes of quite another sort is the increasing frequency with which abandoned farms, vacated land and long-unused irrigation ditches are met with as one goes eastward down the slope of the fan. Not a few vacant houses, especially about eight miles east of Monte Vista, were at one time apparently substantial homes. That profound changes must have taken place within a generation is also made known by the institution of recent drainage districts in the localities of widespread farm abandonment. The nearly stag-

(Photo by Chas. F. Snow, Boulder)

THE NATURAL LANDSCAPE, LOOKING EAST TO THE SANGRE DE CRISTOS. SUMMER STORMS ARE FREQUENT IN THE MOUNTAINS.

A SEEP ZONE IN THE LOWER FAN.

nant water of feeders to open ditches which return the water to the Rio Grande lies on either side of almost every road of importance. Large tracts are artificially drained by covered drains constructed of wood, found to be the most practical material for this purpose here. Locally in all parts of the Monte Vista region, the occurrence of alkali and moist land attests to the closeness of the water table to the surface and the frequent interseeting of the two. Such areas are locally called "seepy land."

The Natural Landscape

Strikingly different are the cultural and natural landscapes of the Monte Vista region—a continual reminder of the great significance of irrigation to this region. The generally monotonous, light sandy surface of the natural landscape is made locally rough by low sand dunes ineffectually held by tufts of grass and bunches of woody bushes. This rough surface bears ample testimony to the strength of the winds which sweep down over it from the mountains, and to the scantiness of the yearly rainfall which, in actual figures, is less than eight inches. Looking westward toward the San Juans the fan slope rises imperceptibly at first to the rolling, gravelly upper slopes which are finally displaced by the steep, parched foothills. Desolation is the keynote of this picture—a barrenness made the more evident by the apparent productiveness and attractive verdure of the irrigated land.

Evidences from Land Uses

Notwithstanding the necessity for irrigation, the farm units here are quite comparable in size to those of the Middle West, the average holding in the Monte Vista region being slightly over three hundred acres. In the uses of the land one may again see the intricate manner in which the cultural landscape has been shaped to harmonize with the environment. Data support the general impression that this is largely a region of stock-raising. Indeed, of the 318 acres of an imaginary composite farm of the Monte Vista region, 48 per cent. would be in native pasture or native grass to be cut for hay, and 42 per cent. in cultivated crops ranging themselves in acreage as follows: peas, potatoes, alfalfa, barley, oats and wheat. Adding to the acreage of native grasses the cultivated crops which are also used for animal feed, it is found that fully 75 per cent. of the land in this locality is

BUILDINGS ON THE MEDANO RANCH, IN THE EASTERN PART OF THE VALLEY, SAID TO CONTROL 150,000 ACRES.

(*Photo by Eben Fine, Boulder*)

LOOKING EAST ACROSS THE VALLEY FLOOR TO SIERRA BLANCA.

used directly or indirectly in the animal industries. Especially striking in this connection are the large acreages of irrigated grass lands, dotted here and there with large haystacks.

Interpretation

Few Present-day Reminders of Original Culture

The Spanish-Mexican culture appears to be one of comparative antiquity—though it actually existed as late as 1850—because as a type it left few marks which permanently withstood the onrush of the more aggressive American pioneer, bringing with him the civilization of the Middle West. The San Luis Valley was, before the latter's arrival, a region of far-flung stock ranges, of widely spaced ranch houses, of Mexican plazas distant scores of miles from one another in parts of this intermontane valley as large as the state of Connecticut, which had been partially divided into great land grants.

This extension of Latin civilization northward into Colorado was fostered by the Mexican Government as a feeble display of power in a peripheral region. It was made possible by the irrigation of native grass lands with water easily taken from the smaller streams issuing from the mountains and crossing alluvial fans or cones at their bases. In certain remote portions of the valley the American modification of this culture, little changed from the original, still persists. Elsewhere, at least within the Monte Vista region, this earlier culture is observable only as a weak infusion in the present-day cultural landscape, adding to it bits of charm and picturesqueness, and little else.

By and Large a Wintering Place for Livestock

The characteristic which seems to penetrate all phases of the cultural landscape in both countryside and village is the organization of economy around the livestock industry. The chief activity of the region through two stages of culture

—and its only one during the first—it is indicative mainly of a restrictive rather than a positive environmental complex.

Primarily in this connection, the growing season is about 110 days, a reduction of the normal for this latitude resulting from the seven-thousand-foot altitude and basin conditions favoring air drainage. Certain uses of the land involving a higher net income are thus excluded; as, for example, the raising of corn and certain fruits. At the same time, native grasses grow well under irrigation, so much better indeed in regions underlain by the Rio Grande loam than other plants, that nearly all such land is devoted to this use. These broad expanses of open grass lands as, for example, in the Rock Creek District south of Monte Vista, are called vegas, whose dark green surfaces are in striking contrast to the barren land to which they are frequently in proximity.

However, large herds of cattle can not be maintained on farms whose size must conform to the high value accorded irrigated land. Thus it has become the common practice to drive cattle and sheep to the high mountain pastures of the San Juans for summer feeding, rights having been secured in the National Forest. In the meantime the owner is storing hay to be fed to the range cattle which are returned to the farm in the autumn. Sheep, on returning to the valley in October, are usually turned into the pea fields and finished for market in this way. The field pea provides fodder in this cornless region, while the method of harvesting the crop is indeed simple and easy. Other plants for winter feeding are also raised in this region of scant possibilities, which further suggests the centering of interests around the production of animals. Thus it is that the valley is still essentially a wintering place for livestock.

Land Uses of Past and Present Régimes

The present small acreage of spring wheat represents a survival from the time of first settlement of the valley, while

SHEEP RETURNING FROM THE MOUNTAINS.

THRESHING WHEAT NEAR MONTE VISTA.

the potato is representative of the newer and more delicate adjustments to geonomic conditions.

Wheat, by sufferance of a permissive environment, fulfilled its place in the economy of pioneer days for which it has elsewhere become famous. Stories are prevalent of the crude methods employed here in seeding the wheat crop during early times—of casting the seed broadcast over soil prepared only by stripping it of growth with a steel rail dragged over it—and despite this of phenomenal yields resulting. Finally, diminished profits spelt the decline of this boom period of one crop. Although still the chief manufactural activity of Monte Vista is milling wheat, the mill at Hooper has closed its doors. The only other noteworthy manufactured product of Monte Vista is the "fresno," a kind of grading machine used in leveling land preparatory to its irrigation.

The potato, on the other hand, is in close adjustment to the relative coolness of the summer and the light sandy soils of this as yet pestless region. Production costs are held to a minimum by the widespread use of labor-saving devices for seeding and digging, machines whose use is made possible by the large size of the level fields and by the employment of Mexican labor in bagging the crop. One of the novel sights of the San Luis Valley during the autumn is the covered wagons being driven in from the south by Mexican families seeking contracts to bag the potato crop of some planter. Deprived of this migratory source of cheap and efficient labor, the valley would face a serious if not insuperable difficulty. That the potato is not a perfect adjustment to remoteness is shown by the periods of prosperity which are interspersed with years of distress arising from the equally certain surplus crop of other irrigated districts seeking the same markets.

Sub-irrigation—Causes and Results

The large size of the farm units, that is to say large for an irrigated region, is explained by the considerable acreages in native grass, by the predominance of the animal industries, and by the use, north of the Rio Grande, of a type of irrigation developed in this locality and called sub-irrigation, or, more simply and popularly, "subbing." It is a method of irrigation at once enforced by the dominant use of the land and by the shortage of labor in early times, and was made possible by the height of the water

THE CLOSED FLOUR MILL AT HOOPER.

table and the abundance of water gathered from the San Juans by the Rio Grande.

In its practice, ditch water is used in large amounts to raise the water table and this, in turn, results in an excessive underground supply entering the drainage down the slope. Requiring less labor than the usual process of flooding, it lent itself well to the needs of a region dependent upon large acreages for its best success. Sub-surface water, with which the upper fan slopes are supplied, has found little use for irrigation in this region of abundant surface water, despite its Artesian characteristics. Small plots and gardens are, to be sure, frequently watered with it, after the water has been first warmed in the sun. Convenient also for watering livestock, it is popularly conceived to be an outstanding natural advantage of the region in that industry. Strictly, however, it must be accorded a secondary position in a geographic interpretation. Nevertheless, Artesian water is of the greatest significance as a source of domestic supply. Secured cheaply by sinking wells one hundred feet or so into the sands and gravels of the fan, it furnishes a constant supply for each home and renders superfluous artificial methods of raising water. Its constant low temperature, moreover, provides adequate refrigeration.

Excellent though sub-irrigation has been for irrigators on the higher parts of the fan, it has been ruinous to the majority of those farther east at a lower elevation. In "seep zones," that is at points of issuance of this excess water caused by the truncation of water-bearing strata, waterlogging of the soil and excessive alkali accumulations have resulted. This has led to the condition of abandonment described above. Organized effort has been brought into play in the drainage of these alkali lands in much the same fashion that fifty years ago cooperation was required for its irrigation.

Technique

The above study is the result of a chorographic investigation carried on in the vicinity of Monte Vista in the summer of 1927. So far as the author is

(Photo by Eben Fine, Boulder)

ARTESIAN WELLS ARE COMMON IN THIS PART OF THE VALLEY.

(Photo by Eben Fine, Boulder)

AN EIGHTY-ACRE POTATO FIELD NEAR MONTE VISTA.

aware, this report represents the first attempt to describe and interpret the choroi of an irrigated region. Heretofore efforts in this newer phase of geographic work have been carried on in the humid east, largely because the leading investigators are located there.

The major elements of field technique, as outlined by such pioneers as Sauer, Jones, Finch, Colby, Whittlesey and McMurry, have been found to form a substantial framework for investigations in the arid west. Problems arising from the widely different conditions, however, make certain adaptations necessary.

In the first place, little aid was secured from study before entering the field, a condition which places an even greater emphasis and burden on field work in the west. Detailed historical information was not securable, while the soils and water supply studies made several years ago are now nearly worthless owing to the rapidity with which soil and drainage conditions change in arid regions through their improvement.

The first impulse of the geographer is to make the division between irrigated and non-irrigated land the leading item. This, however, is soon found to be not only impracticable, because land is watered or not for such a wide variety of reasons, but what is more important, such a procedure is not in accord with the spirit of geographic field work as distinct from economic surveys.

In the progress of the study it was found the better practice to place the major emphasis on recognizable geographic types as revealed by reconnaissance. This involves the mapping of environmental and cultural complexes on the same plat rather than the method recommended by Whittlesey. In the present study four types were clearly recognized and defined in terms of soil profile, natural vegetation, depth of

PONCHA PASS, NORTHERN ENTRANCE TO THE SAN LUIS VALLEY.

ground water, type of irrigation, presence of alkali and dominant use. Names given to the types are the Rio Grande Bottoms, the Vegas, the Seep Lands, and the High Lands, each one of these types being accorded a dominant color scheme. It is apparent that no type is pure throughout so that adherence to the simplified color scheme adopted facilitates the reading of the map. When the dominant color scheme of one type gives way to that of another, boundary lines between types may be drawn, thus simplifying one of the knottiest problems in geographic work.

This scheme would seem to be adaptable to most lands in which irrigation is a permanent institution.

THIS FARMSTEAD HAS SEEN BETTER DAYS.

TRANSPLANTATION OF ORGANS

By Professor THEODORE KOPPÁNYI
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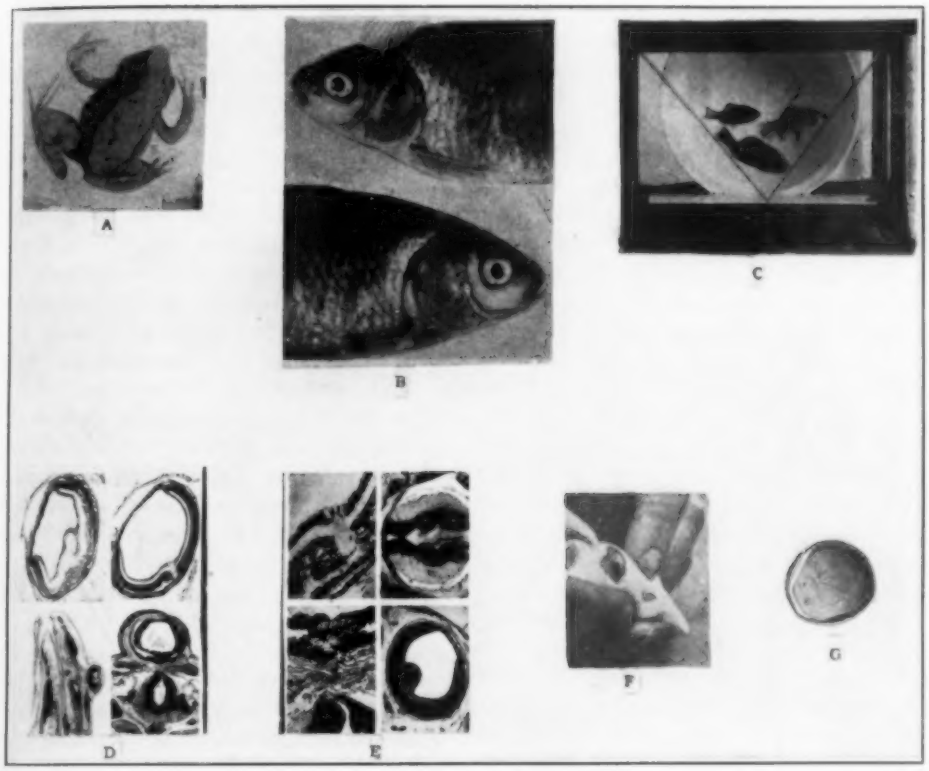
TRANSPLANTATION, or grafting tissues and organs, is an ancient art, and even old East Indian physicians are reported to have achieved remarkable results with grafting portions of the skin. In our own advanced age the grafting of skin, periost, fatty tissues, etc., became standard medical procedures, mostly used to cover up bodily defects for cosmetic purposes.

But transplantation of intact organs is not as easily accomplished, for the taking of the graft depends upon its early vascularization, and unless this is accomplished, the graft degenerates rapidly and at its best becomes a foreign body incorporated in the host, without any function whatever. The graft thus must be saved from destruction through early blood supply, which, of course, must be established before the cells composing the organ are irreparably damaged. It is obvious that an early efficient vascularization of a large organ presents more difficulties than that of a thin layer of tissue. There are two other factors of equal importance which militate against the taking of the graft: the invasion of the grafted tissue or organ by the professional destroyers of the body, the wandering cells; and the defunctive regenerative power of the graft, for higher animals exhibit very little faculty to regenerate and regeneration is essential in establishing more intimate connections between graft and host. Fortunately, however, even higher mammals are able to *repair,* and wound-healing and some regenerative power of tissues within the organ suffice in many cases to secure the taking of a larger graft.

Many attempts have been made to ensure successful grafting of organs, but they have met mostly with only temporary success. A great technical innovation was introduced by Murphy and Carrel, who actually established immediate blood supply of the grafts by suturing the blood vessels of the graft to the blood vessels of the host. But even Carrel's results were not satisfactory and he soon lost interest in the problem, turning his attention to the question of tissue culture.

Although not essentially interested in methods and technique, I turned to the problem of organ transplantation because I needed this method in the hot pursuit of certain problems which troubled me a great deal. In 1920 I became fascinated with the perfect color adaptation to environment exhibited by certain species of fish and amphibia. If you place such an animal in a dark dish, its skin becomes dark; if you put it into a white one, it becomes light. This process is sometimes slow, sometimes astonishingly quick, according to the species. Now if you remove the eyes or cover them with black cloth, the animal ceases to show this nice adaptation to the color of the environment and assumes a uniformly dark, almost black color which is not responsive to external stimuli. The problems which confronted me were how and to what extent are the eyes concerned in this remarkable phenomenon. It was clear that the color of the environment was transmitted through the eyes, the question was whether this transmission is a purely chemical process, or whether it requires transmission through the optic



EXPLANATION OF FIGURES.

A. Frog with an eye transplanted on the site of the auditory organ. Operation performed by R. M. May at the Comparative Anatomical Laboratory of the Sorbonne. The graft established connections with the central nervous system. B. Goldfish with transplanted eye. The picture was taken thirteen and one-half months after the operation, which was performed by Professor Ask at Lund, Sweden. C. The picture shows the dark color of the blind fish and the lighter color of the fish with transplanted eye (Koppányi). D. & E. Histological demonstrations of regenerative processes in the transplanted eyes of Urodels. The experiments were performed by R. Matthey, of the University of Geneva (Switzerland). F. A mouse eye which has been transplanted into the eye socket of an albino rat. The graft took, but showed no evidence of function (Koppányi). G. The fundus of a transplanted eye of the rat, 9 months after the operation (Koppányi). The central artery of the retina has been injected with Berlin-blue. The eye is one of those successful grafts which showed functional recovery.

nerve to the higher optical centers; in other words, is it dependent upon vision? To settle this question I had to go back to the almost discarded method of organ transplantation, and more than that, I had to select the most delicate organ for such purposes—the eye.

Just a few words about the method by which I achieved permanent results, not only with reference to the eye, but also to all the other organs I had to deal with later on. My own and other people's experience taught me soon that the best results are obtained if the graft is not fastened to the host by any artificial means. So I relinquished all sutures, artificial compression, etc., and relied only upon the natural ability of the graft to remain *in situ*. By this technique the wound healing and regeneration could proceed without any delay, having no artificial barriers to overcome. Returning to the eye, I transplanted the eyes of larval and young amphibia on the neck or dorsal region of a host of the same species, and found that those transplanted eye-grafts did not only take but also regenerated a perfect retina and even an optic nerve. The regenerated optic nerve sometimes grew into the nearest spinal ganglion. Although the transplantation of these eyes was successful, it answered my question only negatively. For if I removed the own normal eyes of the host, the transplanted eyes on the back or neck did not prevent the appearance of the dark color characteristic of blind animals, nor did these animals show any ability to copy the color of the environment. I concluded, therefore, that chemical changes set up within the eye and transmitted through the circulation or through non-specific nervous pathways could not be responsible for the phenomenon of color adaptation.

When I undertook the next step in my investigations I could not help feeling a horror at my blasphemy and lack of reverence that I dared to replant the eye into its natural environment, into the eye socket or orbit, and had the audacity to expect, or at least to hope, that I might be able to establish a connection between the visual receptors of the eye and the higher optical centers. Yet I performed the experiment on a large number of fish and amphibia. The results were astonishing. The dark color of the blind animal disappeared in about three months after the transplantation and at about the same time they began to exhibit their lost ability to adapt themselves to the color of their environment. This successful experiment gave me the clue to the whole problem. The color adaptation of fish and amphibia is actually due to the transmission of the color of the environment through the natural optical pathways. Having accomplished this I didn't feel I should stop. The results achieved suggested very strongly that not only the color adaptation but also the vision itself was restored by the transplantation of the eye into the eye socket. Subsequent experiments proved that this assumption was not unwarranted, for the animals with transplanted eyes began to show positive phototaxis to weak light and negative phototaxis or photophobia to strong light. Moreover, they succeeded in chasing and even capturing their prey in a way which only normal animals can do. Blind control animals were never able to learn that. But even if a glass jar was placed between the animal and the prey, the animal with transplanted eye and the normal animal were able to aim directly at the prey outside of the glass jar, whereas blind animals paid no attention to it. The anatomical findings corroborated the biological evidence. The painstaking researches of Professor Kolmer revealed that the histological appearance of the eye graft was almost normal and at any rate all the elements were present which are necessary to optical functioning. He also showed that the cell bodies in the gan-

glionic layer of the retina regenerated nerve fibers which grew through the chiasma into the centers in the mid-brain.

Having solved this problem in fish and amphibia, I proceeded to inquire whether eye transplantation can be successfully carried out in mammals. I chose the rat, for this animal was then available in large quantities and because from surgical point of view its eyes are very readily accessible. Briefly, in this species too I obtained successful results, although in a much smaller percentage than in amphibia. Here, too, I found return of vision and regeneration of the optic nerve of the transplanted eye. Later on even a rabbit was added to the list of the successful experiments. Transplantation of the eye, therefore, in every class of the vertebrate kingdom, is a practicable procedure which may lead to regeneration of the optic nerve and recuperation of vision.

Naturally, the critical scientific world did not let my communications be passed unchallenged. Several and even severe criticisms were heard now and then, and the validity of the results was doubted. This was very fortunate, however, because it led many investigators to repeat my experiments. And it so happened that they came to conclusions similar to mine. I could discuss several papers, all of which affirm my experimental results. Only lately Stone and Ussher reported on return of vision and regeneration of the optic nerve in the transplanted eyes of amblystoma and diemyctylus. On the basis of the experiments just reported, a Belgian ophthalmologist, Weekers, performed the replantation of an avulsed eye in man. The eye was severely injured in the accident and yet the graft took and although vision was not expected, the motility, at least, returned. For cosmetic purposes, therefore, the eye graft became a possibility even in man.

The eye is an organ enclosed in a fibrous connective tissue capsule. This helps the eye graft to protect itself from the invasion of the destroying wandering cells, mentioned already. In connection with other problems I was forced to repeat my transplantation experiments on other organs, similarly protected by a defensive layer. The testis of Urodels, the spleen of the rat, and the liver of the bullfrog were transplanted into the peritoneal cavity and these organs, although not sutured to the host, took with preservation of their original morphological structures. The method which was very efficient in the case of the eye proved to be serviceable in the case of the testis, spleen and liver.

The transplantation of the testis of newts was attempted unsuccessfully by Herlitzka and also by Bresca. I took up the problem again and obtained permanent results. The grafted male gonads of the newts took and even normal spermatogenesis, *i.e.*, the production of ripe spermatozoa, could be observed in the transplants. The male gonads of the newt, *Triton cristatus*, were also transplanted into the peritoneal cavity of females and of individuals of other newts (Pleurodeles, etc.) with similarly satisfactory results.

The spleens of albino rats were transplanted into the abdomen of other animals of the same species. Again the grafts took, essentially preserving their original structure, and certain interesting morphological changes took place in the transplant. The same thing is true of the liver, which was transplanted in amphibia.

Transplantation as a method is a *par excellence* biological procedure and recently proved to be of great value in experimental embryologic investigation. It enables us to discover the hidden potentialities of undifferentiated areas of the embryo; it enables us to find out something about the hidden endochemical activity of an organ; and finally, it enables us to accomplish something there, where organ-regeneration doesn't do the work.

PHYSIOLOGICAL EVIDENCES OF EVOLUTION AND ANIMAL RELATIONSHIP

By Professor CHARLES G. ROGERS

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THE recent work of physicists, chemists and astronomers, dealing with the nature and origin of matter, adds emphasis to the idea that the process of evolution can by no means be limited to what we have been accustomed to call "organic matter," but that it must be applied to our whole universe and that "organic matter" forms only a special case or a series of special cases of the working out of a universal law.

For many years evidences of the evolution of organic forms have been accumulated from a variety of sources. Paleontologists and anatomists have dwelt upon the homologies of various structures. They have pointed to similarities of adult form as indicating similarity of origin and, therefore, of development. Embryologists have shown that there are not only similarities of individual development, but that certain structures have, during the course of their development, taken on forms and functions quite different from those for which they were originally designed.

Little emphasis has been laid upon the contribution which physiology may make in the working out of the general problem. This may be due to the fact that the chief interest of most of our physiologists is not in general biology, but in a very specialized and extremely limited portion of the field, mammalian physiology. This may be another instance in which closeness to the multitudinous details of highly specialized functions has led to a loss of perspective.

It is not the purpose of this paper to present much in the way of new evidence, but by taking advantage of some scattered bits of evidence to call attention to what seems to be a neglected field in the hope that others, better qualified, may continue to develop the point of view.

We have, of course, no information as to how living matter came to be. From what we know of its structure, composition and behavior we may be able to make certain conjectures as to the conditions existing when living matter first appeared. The origin and evolution of living matter is evidently closely associated with the origin and evolution of non-living matter. Here at the very beginning of life we must recognize the fundamental unity of non-living and living. The living matter is made up of non-living constituents. When our friends, the physicists and chemists, have been able to fill in more completely their fabric of knowledge concerning the building up and combining of non-living molecules, we shall be in better position to tell how living matter came to be. Certain facts seem to be sure. There must have been light, and the temperature must have been above the freezing point of water and below the coagulation point of the particular compounds which make up the bulk of the living substance. The evolution of matter had gone so far that there already existed the elements of the lower atomic weights and many of the combinations of these. Oxygen, carbon dioxide, nitrogen and simple nitrogen compounds were in the atmosphere, along with water vapor.

The molecules of inorganic crystalline substances have a definite configuration. They are, under the conditions existing

stable structures. The molecules entering into the composition of living matter may also be stable, but the configuration of the aggregate which we call living substance is very unstable. From the growth of the salt crystal in saturated solution to the growth of the living substance is a long step, for the two are wholly different processes. How may the latter have been brought about?

Try to imagine the conditions upon our planet before any life appeared. The sun, the center of our solar system, was much younger than now. Astronomers tell us that the stars have a definite life history: that they have a beginning, youth, middle age, old age, and finally cease to be. Our sun appears to be well along in its cycle. It has passed through that period in which it radiated most energy. These radiations have been and still are in part electrical, in part visible light and ultra-violet radiations, in part infra-red rays, in part radiations of very short wave-length. The younger stars, the whitish and the bluish-white ones, are characterized by extensive radiations in the ultra-violet region of the spectrum. Such radiations were presumably more abundant upon our earth in the earlier days than now. Certain radiations of very short wave-length, emanating from some unknown source, are even now detectable in our atmosphere. They may have been and probably were more abundant at an earlier period. Their presence is held to be indicative of the continuous production of helium, hydrogen, oxygen, etc., out of the raw materials, the electrons.

Imagine the land, entirely devoid of vegetation of any sort, made up of binary combinations of elements, at a tropical temperature, water-soaked by frequent rains, covered by an atmosphere heavily laden with moisture and containing oxygen, a higher content of carbon dioxide than is now known (the product of volcanic activity), nitrogen and very simple nitrogen compounds. Imagine heavy storms—water rushing down through the valleys into the sea and on its way dissolving various inorganic substances, and carrying along relatively less soluble material in the form of finely divided particles, a suspension so finely divided as not readily to settle out upon standing—colloidal material, if you please. Let the energy of the sunlight with its excess of ultra-violet rays bombard this colloid-like system. At the colloidal interfaces adsorptions of carbon dioxide, gaseous nitrites, oxygen, etc., must occur. At these interfaces these simple substances are brought into molecular relations with each other. A simple catalytic system is at work. Out of the complex it is difficult not to assume the building up of ternary compounds of carbon, oxygen and hydrogen, such as formaldehyde and simple carbohydrates, and then of simple quaternary nitrogenous compounds, such as formamide. New substances come into being because of the activity of the colloid-like solution as an energy transformer. The elements involved are the carbon, oxygen, hydrogen and nitrogen; then molecules of sulphur, phosphorus and iron are added to the combination. Water, the universal solvent, is not only the solvent in the living substance, but has an important part in its structure, for it has become an integral part of the colloidal substance.

The colloidal material responsible for bringing about these first syntheses may be thought of as a simple catalyst, very generalized in its character and behavior and in the products of its energy transformation. Some of the earliest appearances of what we think of as living matter must have been the combination of molecules into forms capable of acting as energy transformers—substances which could make use of the energy of the sunlight in effecting various molecular combinations. We have at the present time such a substance in chlorophyll. There is no evidence that the

earliest synthetic agent of this sort was green in color. In fact the suggestion has been made that the green color has been developed as a protective device to assure the non-destruction of a more fundamental catalytic substance by the light rays.

From the simplest colloidal complex capable of self-continuance to the simplest amoeba with which we are acquainted represents a wonderful evolutionary history, which may well have occupied as long a time as the evolution from amoeba to man. During this period there must have been elaborated amino-acids and various combinations of these to form proteins, various carbohydrates, fats, nucleic acids and enzymes. It would be absurd to assume that all the bits of matter of the kind described, in which organic syntheses occurred, could survive. Many of them would carry on within themselves processes which would prove to be self-destructive. It is interesting to note that only those forms have survived to the present on which there were developed membranes to serve as separations of the living substance from the liquid environment. Evidently much can be said about the cell membrane as a factor in survival. Various cell mechanisms came into being. There were developed mechanisms for regulation of water content, for the selective and constructive work of secretion, for cell division, for ensuring in the daughter cells living matter of the same sort as that which composed the mother cell. Survival came not to be a haphazard affair, but the result of an orderly series of physical and chemical phenomena. These various mechanisms did not all come into being at once. They did not always appear, perhaps, in the same order. They did not always take the same form, nor were they always made up of the same components. The bits of unstable matter in which synthetic processes occurred were in constant interaction with their environment. Since there were variable environments, there were variable synthetic complexes. We have been accustomed to speak of the origin of living matter. It would be better, and probably more in line with the facts, to speak of the origins of living matter. In various places at the same time such syntheses may have occurred. Also, there is nothing to oppose the suggestion that at many times, in many places, under a great variety of conditions, such combinations of matter capable of undergoing spontaneous change and of acting as energy transformers may have had independent origin. This would not only make great variety of living matter possible; it would make it inevitable.

It would be safe to assume, too, that these different bits of living matter did not exist together in a perfectly harmonious fashion. Some of them were inimical to others. Some may have played such parts as are now played by the filterable viruses. Only those forms of living matter could exist which developed some form of immunity against the attacks of other unfriendly forms.

The forms of living matter capable of carrying on these organic syntheses, and of maintaining their own integrity, are those which appear as colloidal systems of a complicated nature, so that they appear at one and the same time to partake of the nature of true solutions, emulsions, colloidal sols and suspensoids, and to have so delicate a colloidal balance as to be rather readily transformed from the liquid sol condition to the more viscid gel condition, and vice versa.

One of the very strongest evidences of the essential unity of living matter is that we have no knowledge of life apart from protoplasm. This protoplasm, from whatever source, is always a substance containing water, salts in solution, and composed largely of proteins, which are present either in the form of an emulsion or as a suspension.

This early living matter originated in the sea, or, perhaps more strictly, in the littoral waters. It was, therefore, at the time of its origin adapted to the existing conditions. Otherwise it could not have continued to exist. What were these conditions? It seems that we may be able to reconstruct to some extent a picture of the situation. Living forms adapted themselves to their environment in a variety of ways. Let us mention a few of them.

(1) *Temperature:* The temperature of the organic matter was essentially the same as that of the water in which it originated. It was, therefore, of a temperature between the freezing point of water and the coagulation point of the colloidal complexes of the living substance. The temperature of the water must have shown then, as now, a daily cycle, rising during the daylight hours until the latter part of the afternoon, and then falling during the hours of darkness until the early morning. Such a cycle of temperature changes now exists not only in the waters of the tropical ocean, but in the bodies of the so-called warm-blooded animals. It would hardly do to say that this daily temperature cycle of the higher animals is a direct hangover from the daily temperature cycle of the early ocean, and yet it might be.

(2) *Concentration of Salts:* The sea water contains at the present time about 3 per cent. of salts in solution. This represents an accumulation of millions of years. When matter first became organized into forms capable of carrying on orderly energy transformations and of providing for self-continuance, the water of the sea was much less salt than now, though it may have been somewhat more salty than present-day freshwater streams and lakes. The living matter then was adapted or adapted itself to the conditions existing.

An examination of the body fluids of various groups of animals reveals the fact that in the animal kingdom there has been a rather steady gradation in complexity from the very simple to the very complex as we pass from the lower forms to the higher. It is a long step from the conditions existing in the body fluids of some of the simpler animals—and which must have existed in the body fluids of the earlier metazoa, up to the exceedingly complicated conditions which now exist in the bloods of the mammals. In the lower and earlier forms the body fluids consisted of water in which were dissolved some small amounts of salts. In the bloods of the higher animals of to-day water is still the solvent in which there are to be found in solution:

the chlorides, sulphates, carbonates } of { sodium, potassium, calcium

proteins
- serum albumen
- globulin
- fibrinogen

prothrombin
antithrombin

foods
- amino acids of a number of kinds
- fats or fatty acids and glycerine
- sugars

oxygen
carbon dioxide

wastes
- urea
- uric acid
- creatine
- creatinine

hormones
- gastric and pancreatic secretins
- thyroid
- adrenal
- pituitary
- ovarian
- testicular
- thymus
- pineal

antibodies for measles, mumps, smallpox, typhoid, scarlet fever, etc., etc.

The body fluids pass through a regularly graded increase in complexity which may be briefly outlined as follows:

Water, containing the salts of the sea in solution.

Hydrolymph, a watery fluid which carries nutriment to organs and tissues and removes wastes. This fluid sometimes contains no food substances in solution, though it may hold them in suspension, or in some cases it may contain dissolved proteins or their products. As a rule it has no respiratory function other than that which might be carried on by the water alone.

Haemolymph is a circulatory medium less watery than the hydrolymph. It contains a richer supply of proteins. It is not only nutritive in function, but also frequently respiratory in character by virtue of the respiratory pigments which it contains, and corresponds to both the blood and lymph of the higher animals.

Blood, which is the chief circulatory fluid of the higher animals. It is the most highly differentiated and complex circulating mechanism found in the animal kingdom and serves in the following functions: to carry to every part of the body the materials for its sustenance; to carry away from the tissue cells all wastes; to carry to all parts of the body hormones and internal secretions; to serve as an agent in the temperature regulation of the body; and to protect the organism from invasion and destruction by microorganisms.

Osmotic Pressure of Body Fluid

As the salt content of the sea water has increased, those animals of the simpler types which have remained in the sea have gradually adjusted themselves to the changing conditions of their environment. One may almost say that the bodies of these lower animals are wide open to the sea. As a matter of fact this is not strictly true, for it appears that most of these lower forms of animals possess body fluids of very slightly higher osmotic pressure than that of the sea water in which they live. The relative total salt content of sea water and of body fluids may readily be compared if the depression of the freezing point of the liquid below that of distilled water be determined. This depression of the freezing point can be expressed in terms of degrees Celsius or translated into atmospheres of pressure or concentration of solution, as one may prefer to do.

Reference to the table indicates that the forms showing the lowest osmotic pressures (least depression on freezing point) are the fresh-water molluses, worms and crustacea. Then come in ascending order the reptiles, amphibia, fresh-water bony fishes, mammals, birds, marine bony fishes, Atlantic Elasmobranchs, Atlantic invertebrates, Mediterranean Elasmobranchs and Mediterranean invertebrates.

An analysis of the facts seems to indicate that there is some causal relation existing between the osmotic pressure of the sea water and the osmotic pressure of the bloods of the different groups.

Depression of Freezing Point in Degrees Celsius

	Mediterranean Sea	Pacific Ocean	Atlantic Ocean	Fresh Water	Terrestrial Animals
Sea Water	−2.29	−1.924	−1.82	−0.03	
Mammalia			−0.64—0.74		0.56—0.60
Aves					0.66—0.75
Reptilia					0.46—0.56
Amphibia					0.56—0.76
Pisces	−1.04—1.05	−0.762	−0.75—0.86	−0.51—0.68	
Elasmobranchia	−2.29—2.44		−1.87—2.03		
Cyclostoma		−1.966			
Mollusca	−2.24—2.44			−0.15—0.21	
Insecta					−0.95
Crustacea	−2.29—2.36		−1.82—1.90	−0.49—0.80	
Annelida				−0.43	
Coelenterata	−2.195				

Undoubtedly the sea water in which life originated was relatively dilute as compared with the sea water of the present time. This sea water became more and more concentrated as various salts were washed down from the land into the sea. At various periods some of the animals living in the sea migrated up the streams and came to live in water which was less concentrated in salts, others emerged from the sea and took up a terrestrial habit of life. It is possible that there was a period in which the salt concentration of the sea water increased rapidly or that some other factor led to a great migration or series of migrations of animals from the sea. Overpopulation of restricted portions of the sea may possibly have been a factor. At any rate, evidence is not lacking that the ancestors of many species, representing several phyla, left the waters of the sea at nearly the same period—a sort of organic explosion. The immediate causes of such a migration must have been physiological. Those animal lines which remained in the ocean have been for generations continuously subject to the gradually increasing concentration of salts in the sea water. The accompanying figure (Fig. 1) presents in a graphic form a brief summary of information concerning the freezing points, and therefore the osmotic pressures, of the body fluids of various animal groups, and a suggestion is offered as to the possible explanation of some of the facts. It will be noted that, in this figure, depressions of the freezing points of bloods and of sea water are represented as abscissae, and that duration of time is indicated as ordinates. No effort is made to indicate any definite lapses of time. The fresh-water molluses show a depression of the freezing point which indicates either that they migrated from the sea into the fresh water at some very early period or that they have developed little power to maintain in the body fluid a salt concentration different from that of their environment. The fresh-water worms show a decided increase in the salt content of the blood. The reptiles show a salt content slightly higher than that of the fresh-water worms. The fresh-water fishes, the mammals, the amphibia, the birds, all have salt concentrations of very nearly the same values, which slightly overlap each other and which are only very slightly below the salt concentrations of the bloods of the marine bony fishes taken from the North Atlantic. It seems entirely possible that the ancestors of these forms so closely grouped must have emerged from the waters of the sea at approximately the same period, as far as salt concentration of the sea is concerned. The mammals and birds apparently have attempted to maintain in their body fluids through all the succeeding generations approximately the same concentration of salts as that to which their ancestors were accustomed in their original marine habitat. The fresh-water fishes and amphibia show a somewhat wider range of salt concentrations than do the birds or the mammals. This condition can, perhaps, be accounted for by the fact that the animals have for the most part lived continuously in an aquatic environment. They have maintained with more or less exactitude the salt concentrations of the bloods of their ancestral forms, concentrations which were presumably very similar to the concentrations of the sea water in which they lived. The marine fishes, both of the open ocean and of the Mediterranean Sea, show osmotic pressures a little less than one half the concentration of the water in which they live. The bloods and body fluids of the marine invertebrates, however, have salt concentrations which equal or are very slightly in excess of the concentration of the sea water. Just how far it is justifiable to seek to explain the salt concentrations of the bloods of all terrestrial

forms upon this basis is, of course, somewhat uncertain. It appears in each case that the blood is in a condition of equilibrium with the external medium, even though it may differ from it to a considerable degree. It can also be shown that any change in the osmotic pressure of the external medium brings about a corresponding and compensating change in the osmotic pressure of the blood, to a greater or lesser degree in the different groups, until a new equilibrium is established. Such an equilibrium is established and maintained by the cells which come into contact with both liquids, blood and water, namely, the epithelial cells of the gills. The evolution of cells and cell membranes capable of maintaining such differences of osmotic pressure as are shown in these cases presents a problem worthy of much further study.

It is not necessary at this time to go into a discussion of the physiology of the adaptation of an animal to the osmotic conditions of its environment. When living matter first appeared in the water of the sea it was undoubtedly adjusted to the salt content of the water as it existed at that time. The salt content was being continually increased through the addition of salts washed down from the land into the sea. These additions must have accrued very slowly, indeed. The fact that the living organisms continued to exist is itself an indication of the fact that there was a continual adjustment of the organisms to the increased concentration. This adjustment has continued until it is now found that organisms have become adapted to living in a salt solution, the concentration of which may be equal to or in excess of that of a five eighths molecular NaCl solution.

But not all animals live in the sea. At different periods in the earth's history there have been migrations from the sea to the fresher waters, and also from the sea to the dry land. Many of these migrations took place relatively early in the history of animal life. The animals taking part in these migrations evidently made the attempt to continue in their bloods the cellular environment which had been theirs before the migration. This environment involved both water, containing a certain concentration of salts, and salts in definite relative proportions to each other. The blood plasma of the higher animals, therefore, represents the original aquatic environment of the cells as to the total concentration of salts, and should contain all the elements originally entering into the composition of that environment. As we shall see, it may contain much more than the original environment, for during the ages there have been taken on new substances, providing for new functions, or great extensions of old ones. (For example, the development of the thyroid gland in the higher animals may be explained as an attempt on the part of the organism to preserve in the body fluid of the animal the iodine content of the sea water, and so regulate the metabolic activities of the cells.

Composition of Body Fluids

Unfortunately, complete analyses of the body fluids of the lower animals are not yet available. We have good reason to believe, however, that they approach more nearly the composition of the sea water than do the bloods of the higher animals. Only very recently has the importance of the substances existing only in very small amounts in body fluids been recognized. Such substances may exist in the body fluids of the lower, invertebrate animals. Up to the present they have not been recognized.

In all forms of the metazoa in which body fluids exist there is a remarkable balance between the relative numbers of molecules of sodium, potassium and calcium of the circulating medium, the ratio being in general of the order 100 : 2.2 : 1.5–2.5. In the sea water mag-

nesium salts occupy a prominent place, and they appear in the bloods of the lower forms also. Among the higher animals the magnesium plays no important part, and it would almost seem that the ancestors of these animals had taken their departure from the sea before any considerable amount of magnesium existed in the sea water, or that these organisms have the power to exclude magnesium from their bodies. It is to be noted, however, that while the body fluids of many groups of animals contain sodium, potassium and calcium salts in essentially the same proportions as those in which they exist in sea water, the body tissues have the power to store up or to exclude these substances. Such storage or accumulation may occur whether the organisms be unicellular or multicellular, and indicate a gradual specialization upon the part of the secreting cells. Such specializations of a chemical sort appear among diatoms, desmids, Foraminifera, Radiolaria, silicoflagellates, sponges, Alcyonaria, Anthozoa, Bryozoa, etc., as well as in the higher groups. The fact that the specialization is very real is shown by the tremendous amounts of material secreted from very dilute sea water. For example, Clark has shown that the protozoa of one family deposit 1.4×10^9 metric tons of calcium per day. Numerous other similar cases might be mentioned.

Hydrogen-ion Concentration of Sea Water and Body Fluids

It is only within comparatively recent years that biologists have come to appreciate the importance of some of the less evident conditions which enter into the environment of living organisms. One of these has to do with the degree of acidity or alkalinity or, as we more frequently refer to it, the hydrogen-ion concentration of the medium. The sea water, by means of the various salts which it contains, maintains a very definite and very constant alkalinity. This is best expressed in terms of Sorensen's nomenclature, in which the symbol pH 7 represents the neutral point, and in which a numerical reduction means an increase in acidity, and a numerical increase a reduction in acidity and an increase in alkalinity. It has been found that the following figures represent existing conditions in animals of the phyla mentioned:

Sea water	pH 7.09–8.02
Body fluids:	
Coelenterates	8.48
Worms	7.25–7.79
Echinoderms	7.27–7.76
Molluscs	7.23–7.54
Arthropods	7.38–7.62
Tunicates	6.56
Fishes	7.54
Mammals	7.40–7.62

It is to be noted that in almost every case the pH is on the alkaline side of neutrality. Measurements made upon the living protoplasm of various cells indicate that the protoplasm is, on the whole, more acid and less alkaline than the medium in which the cells live. Amoeba protoplasm has a pH of 7.6; the protoplasm of four species of Echinoderm eggs, one species of Tunicate egg and one species of Polychaete worm egg, all show a pH of 6.6. When these eggs died and began to cytolize the pH increased to 4 or 5.

Blood Pigments

Increase in size and complexity of metazoan bodies was made possible only through the development of mechanisms providing for the rapid distribution throughout these bodies of the required supplies of food and oxygen, and for the elimination of wastes. Increase in size and complexity of the animal body has been associated with a relative reduction in the volume of blood contained within the body, and the activity of the animal seems to be correlated with the ability of the blood to carry oxygen. This re-

duction in volume has been coincident with developments along two lines: first, increase in the efficiency of the circulatory apparatus, so that the fluid is carried more rapidly through the body; and, second, an increase in the efficiency of the blood as an oxygen carrier. It will be remembered that oxygen and carbon dioxide are soluble in small amounts in water or in body fluid, but these amounts are insufficient to meet the needs of an active organism. During the course of evolution proteins, which have a remarkable power of forming easily dissociable compounds with oxygen at ordinary atmospheric pressures, have developed. These are the so-called blood pigments. Some of these are much more effective as oxygen carriers than others. The oxygen-carrying power of the blood will then depend upon the particular pigment which it contains and upon the amount of that pigment which is present. Named in order of importance these pigments are:

	Color	Metal present	Distribution
Haemoglobin	red	iron	widely
Haemocyanin	blue	copper	molluscs, crustacea
Haemosycotypin	blue	copper, zinc	molluscs
Chlorocruorin	green	iron	worms
Haemerythrin	red	iron	worms
Achroglobin	colorless	manganese	molluscs
Pinnaglobin	colorless	manganese	molluscs

Of these pigments, haemoglobin is by far the most important. It is a protein substance containing probably as many as two hundred amino-acid links in its molecule, which has been estimated to have a molecular weight of about fifty thousand. Of this substance there is a great amount produced daily by living animals, the amount being built up daily by human bodies being estimated at ten thousand tons. This substance represents the highest degree of evolution by living matter of an oxygen carrier. The substance which ranks next to haemoglobin as an oxygen carrier is haemocyanin. This has about one fourth the oxygen-carrying power of haemoglobin. The haemocyanin molecule is one of almost unbelievable size, with a molecular weight of five millions. This figure is estimated to be correct to within five per cent.

All the blood pigments of the lower animals are dissolved in the blood plasma, but among most of the vertebrates the haemoglobin of the blood is held within the walls of minute cells, the red blood corpuscles. It will be readily acknowledged that material dissolved in the blood plasma would be more likely to be lost to the organism than material carried in cell envelopes. It seems safe to assume that the habit of enclosing small amounts of haemoglobin in envelopes and of transporting them through the vascular system is an acquired habit. The suggestion is made that this habit is an outgrowth of a possible symbiotic relation that may have existed far back in ancestral history, in which pigments similar to the pigment radicle of haemoglobin may have been discarded by various tissue cells as wastes, only to be picked up as possible food substances by invading protozoan cells. These cells, wandering about through the tissues, would have served to carry the pigment, with its combined oxygen, to the more distant parts of the organisms, where under reduced oxygen tension the oxygen would be released, to the benefit of the host. This habit, once acquired, can easily be imagined to have led not only to a conservation of pigment material once cast aside as waste, and now found valuable, but to an increased production of this valuable pigment material for its own sake as a factor in survival.

Blood Coagulation

A physiological process of great importance to the individual, and likewise to the race, is that of blood coagulation. One needs not to be told that any considerable loss of blood is detrimental to the life of an individual. This is especially true in the case of those animals in which the percentage, by weight, of blood has been greatly reduced. In the higher organisms the process of clotting involves a very carefully balanced series of chemical reactions, the explanation of which involves excursions into analytical, organic, colloidal and physical chemistry.

If it is permissible to judge from what may be seen in a survey of the clotting function, passing from the lower animal forms toward the higher, it is possible to say that very early in animal history there began to be developed methods of conserving the blood supply. At first these methods were very simple. One very early method consisted in the massing of the colorless corpuscles of the body fluid at the point of injury. These cells were equipped with long protoplasmic processes or arms reaching out from the central body mass. The processes of one corpuscle became entangled with those of another and another and another, until there was a purely mechanical blocking of the blood flow. Such blocking was not, however, very efficient, and a great deal of blood might be lost before the flow became checked.

Apparently the next step in the process of evolution occurred when the entangled cells began to undergo a sort of chemical change which left them as an agglutinated mass of protoplasm in which all semblance of cell boundaries had disappeared. This stage appears to have been closely followed by one in which there occurred within the cell bodies the secretion of a substance which, when released from the entangled, agglutinated cells, gave rise to a fibrin-like substance, cell fibrin. This substance is probably not at all related to the substance known as fibrin, which is a normal component of mammalian blood. The cells which secreted this cell fibrin were somewhat more specialized than the blood cells which had preceded them. They were more sensitive to changes in their environment, and certainly did a type of chemical work which had not hitherto been accomplished. Under conditions so changed as not to be normal, these cells disintegrated and gave up to the blood stream the fibrin-making material which they contained. The swelling and entangling of this material with other elements of the blood constituted a more adequate block against blood loss. Another step was taken when there was added to the chemical constitution of the plasma a substance which could be made to coagulate under the appropriate conditions. At first, this coagulation of the plasma was very slow and uncertain. In the higher animals the coagulation of the plasma has now reached a very high degree of perfection, and involves the interaction of substances in solution in the plasma with substances produced in tissue cells, which are released when the blood vessels are injured, and substances produced in certain of the blood cells, which are exceedingly sensitive to changes in their environmental conditions. This chemical mechanism is now under normal conditions so effective as to bring in a few seconds results which in the lower forms would have required as many minutes or an even longer period.

Blood Reactions

A line of investigations which has already yielded some positive results, and which promises much for the future, is that of precipitating and agglutinating effects of various blood sera upon other bloods. It has been shown that, while during the course of evolution the de-

scendants of a common ancestor may have undergone such changes of form and structure as to make it almost impossible to point to direct evidences of common ancestry, there still remain in the bloods of many animals some common property or properties which may render it possible, through biochemical reactions, to determine their relationships. Professor Nuttall writes:

> A perusal of the pages relating to the tests made upon the many bloods I have examined by means of precipitating anti-sera, will very clearly show that this method of investigation permits of our drawing certain definite conclusions. It is a remarkable fact, as I stated on a former occasion with regard to my results with the Anthropoidea, and this applies to other groups of animals, that a common property has persisted in the bloods of certain groups of animals throughout the ages which have elapsed during their evolution from a common ancestor, and this in spite of differences of food and habits of life. The persistence of the chemical blood relationship between the various groups of animals serves to carry us back into geological times, and I believe we have but begun the work along these lines, and that it will lead to valuable results in the study of the various problems of evolution.

In 1907 it was pointed out that there is also an incompatibility between the bloods of different human beings. Since 1910 human beings have been classed in four groups, the blood of only one of which, group four, including about 40 per cent. of the population of western peoples, can be used for transfusion into members of all groups. There is still the possibility that these groups may, after further study, be subdivided.

More recently, Landsteiner and Miller have shown that the haemagglutinins form even better means for distinguishing blood relationships than the precipitins. Racial differences between whites and Negroes are less, if existent, than those between the bloods of man and the anthropoids. Serological differences between man and the lower monkeys are the same as those between anthropoids and the lower monkeys. Also they were able to show from a study of thirty-six species of lower monkeys that there exists a correspondence between the distribution of a certain haemagglutinin and the place of the species in the zoological system. This is evidently a line of investigation which should be followed through with most extreme care and thoroughness.

Chemical Actions in Living Matter

It is customary to speak of the chemical changes which take place in living matter by using the term "metabolism." This includes a great variety of chemical operations, such as oxidations, reductions, deaminizations, coagulations, digestions, syntheses, etc. These are operations which would not occur at all, or only very slowly, except for the presence and activities of certain catalytic agents which we call enzymes. Catalytic actions are characterized by the fact that the chemical composition of one of the products found at the end of the reaction is the same as that of one of the initial substances. Such reactions have been held to be quite specific, but specificity here appears to be more a quantitative than a qualitative relation. For all enzymes the time required to bring about small, equal changes in the substrata is roughly inversely proportional to the concentration of the enzyme. The enzymes are inhibited in their activities by the presence of the products of reaction; they are relatively unstable and retain their catalytic power only within a very limited range of temperatures, and within a rather narrow range of hydrogen-ion concentrations. They have been found to bring about balanced actions, *i.e.*, to operate both to break down and to build up. They are thus able to break down food substances into molecules capable of diffusing through membranes into cells, and then to build up within the cells these small molecules into the more complex carbohydrates,

fats and proteins found in living matter. They also take part in the building up of the various secretions, poisons, etc., produced by many animals. Among the higher animals the number of enzymes is very large, and the work which each does is very narrowly limited. Every cell, tissue and organ of each individual organism is a chemical laboratory in which a considerable variety of chemical operations takes place. The character of the processes depends upon two sets of factors: first, the nature of the substances acted upon, and second, the nature of the enzyme taking part in the reaction. It seems very likely that the differences between the various proteins which characterize unlike species of animals may be accounted for by the fact that the enzymes responsible for the synthesis of these substances are very slightly different from each other, although very similar in many respects.

A complete list of the enzymes occurring in any one of the higher animals would be quite extended. As to the number of enzymes to be found among the lowest animals we have little information. One reason for our lack of knowledge is that an enzymic analysis of animals of microscopic size is not very easy; a second reason is that only comparatively recently has the possible significance of such an investigation been apparent. It is known that the enzymes of the lower forms are more generalized, less specialized, than those of the higher animals. For example, among the protozoa, a trypsin-like enzyme, which acts upon proteins, is found. There are only very doubtful evidences of the presence of pepsin, and specialized enzymes capable of acting upon starches, sugars and fats probably do not occur at all. Among the Coelenterates pepsin, as well as trypsin, occurs; and lipase, amylase, maltase and, in some cases, glycogenase, are present. Among the worms and Echinoderms a few more enzymes make their appearance, and among the Mollusca and Arthropoda a still larger number is found. Among the vertebrates others are added. It appears, therefore, that as one passes in review from the lowest to the highest animals there is an increase in the number of enzymes, and in the degree to which these enzymes are individually specialized for the building up of definite substances out of the raw materials. It may be possible that the high degree of differentiation found among the so-called higher animals is simply an indication of the high degree of specialization to be found among their organic catalysts. The suggestion has been made that enzymes are as varied as the substances constructed by the metabolic activities of animals.

Excretion

It is possible to study in a similar way the processes of excretion and to show that there has been a real evolution in the disposal of wastes. Among the protozoa three methods for the disposal of wastes are found. They may be diffused through the cell wall; they may be deposited in the protoplasm as inert, granular precipitates, or they may be eliminated in solution by the liquid thrown off from the contractile vacuole. The protoplasm of the protozoa has a higher osmotic pressure than that of the water which forms their natural environment. There is, therefore, a continual endosmosis. In the case of marine forms the difference in osmotic pressure between organisms and sea-water is less than in the case of the fresh-water forms. There is, therefore, in the marine forms less need for a water-regulating apparatus. Among the fresh-water forms the contractile vacuoles reach their highest development, and serve to carry off the excess of water which diffuses rapidly into the cells. The water excreted carries with it dissolved substances, such as carbon dioxide, uric acid, etc.

Among the lower metazoan forms there are, in addition to the elimination by diffusion of soluble substances through the membranes of the body wall, wandering cells which take up granular wastes produced by metabolic activity. The wandering cells carry these to some exposed portion of the body, such as a gill filament or to some other area, work their way to the outside, and there disintegrate. This process is referred to as intracellular excretion. The waste materials are then washed away. Or the wandering cells may carry their burdens of wastes to some relatively inactive corner of the animal body, and there deposit their load of rubbish, as in some old attic. There are thus formed masses of accumulated granular wastes, frequently pigmented, which are very characteristic of such forms as the starfishes. This is termed storage excretion.

Among the worms and higher forms these primitive types of excretion become more highly elaborated, and the processes centralized in special organs, nephridia or kidneys, developed for the purpose. The cells upon which devolve the function of forming the excretion granules become, among the worms, very numerous, and the nephridia apparently have the power to carry off such granules as are given over to the coelomic fluid by the disintegration of the excretophore cells. At the same time some of the cells of the nephridial tube appear to be specialized as secretory cells, apparently comparable to some of the glandular cells of the tubules of the mammalian kidney.

Among the higher terrestrial animals there is added to the excretory work of the kidneys another function, that of conserving the water content of the body. This is accomplished through the resorption of water which has filtered through the glomerulus and is on its way to be passed out of the body.

It is interesting to note that while the character and efficiency of the excretory organs have undergone a great evolution, the nature of the substances excreted by the higher forms is not very greatly unlike that of the substances excreted by the lower forms. In this there is evidence that the end products of the metabolism of different animal groups are strongly similar. Among molluscs, for example, there appear as excreted products inorganic salts, creatine, creatinine, taurine, ferric salts and uric acid. Among the Arthropods uric acid is occasionally found and guanin is the most important excreted substance. Among the higher animals urea appears in the urine in the place of uric acid.

Chemical Regulation

In the bodies of adult vertebrates there are certain substances known as hormones, which have profound effects in the regulation of various physiological activities. These substances are produced in any individual in very minute amounts, but must be present if the organism is to function normally. The hormones are relatively simple chemical compounds of the nature of drugs, since they do not lead to the production of antibodies; they are not enzymes, since they are not readily changed by conditions which render enzymes inactive; they are of small molecules, since they diffuse rather readily through animal membranes. Most interesting and important, however, is the fact that the hormones have uniform and constant effects, no matter by what organism they are produced. In fact, some of them have been synthesized in the laboratory and are just as effective as those produced under natural conditions. Our knowledge of these substances is limited almost entirely to those occurring in the higher vertebrates, such as the secretions of the thyroid, parathyroid, pituitary, pineal and adrenal glands. There is evidence that adrenalin or a substance closely allied to it occurs in the leeches,

in some others of the higher worms and in some molluses; but concerning the existence or rôle of other endocrine secretions among the invertebrates very little is known. The evolution of the vertebrates appears to be very closely associated with the development of these chemical regulators. At any rate it seems clear that the highest types of living animals are to a very great degree dependent upon the secretions of these ductless glands for the positions which they occupy in the animal scale.

Reproduction

In no single physiological function is there clearer evidence of evolution than in that of the continuance of the protoplasmic line which we commonly refer to as the species. From the simplest division of an amoeboid cell to form two daughter cells, through the stages of incipient sexualism, up to the most highly developed reproductive processes of the mammals, is a long story of biological attempts to ensure the continuance of the race, to reduce the wastage of energy involved in the building up of valuable germinal material and to conserve the lives of individuals once started on their course of development.

There may be included in this story: the increases in the number of eggs produced, up to several millions per female; the very great excess of sperm produced in most species of animals; the provisions made for ensuring the fertilization of the eggs; the various provisions made for the protection of the eggs during their period of development, such as egg laying in strings or masses, nest building, and egg attachment to parent or to some solid object; increase in the amount of food yolk included within the egg, so as to lengthen the period before hatching; the secretion of shell and albumen coats upon the eggs; the retention of the eggs within the body during a period of development; the gradual evolution of the placentate method of nourishing the embryo during intra-uterine development, and a lengthened period of infancy during which the young are still nourished by maternal secretion.

Nature has experimented upon a vast scale, and we have no reason to believe that the experimental period is passed. It seems clear that some way may yet be found by which the reproductive process may be carried on without the necessity that the reproductive functions or structures shall interfere with other organic functions in such a way as to be inimical to the life of the individual.

Death

As a final line of evidence of evolution from the physiological side there may be mentioned the appearance of death. There is ample reason to believe that natural death is a habit acquired long after matter came to be living. Death is the price which all higher animals must pay in return for high differentiation of cells, and, therefore, of high physiological efficiency.

Reproduction among the protozoa consists in the division of the cell into two. Even among the protozoa the mechanism for such cell division may be extremely complicated. In some forms this process may occur for thousands of generations without any conjugation of different individuals, or endomixis, or any indication of senescence upon the part of the cells. Apparently the process may continue indefinitely. The protoplasm is apparently immortal—barring accidents, and provided that environmental conditions be maintained in a favorable condition. Accidents do occur, however, and environmental conditions for the great mass of individuals prove unfavorable. Food and oxygen supplies fail, poisonous wastes accumulate and check growth and antagonistic organisms prey upon them. Thus the overpopulation of the earth by a single species is prevented.

Similarly, some of the lower metazoa, the sponges, flat worms and some coelenterates reproduce by simple fission or by budding off a portion of the body which reproduces the whole. Here again is no place for death. No residue is left behind in the passage from one generation to the next.

In a similar sense it may be said that the germ cells of the higher animals are immortal. The fertilized egg cells give rise to cells of two sorts, those which form the soma, and germ cells. These germ cells give rise to other germ cells and other somata. This process is repeated over and over and forms a continuous cycle. The soma perishes, but the germ cells live on.

It has been found possible in experiments upon tissue cultures to isolate small bits of embryonic tissues of various kinds in artificial media and to cultivate and keep them alive under observation for a long time. Interesting it is that such cells may retain their embryonic characters for many times the natural lifetime of the species which they represent. It appears probable, therefore, that the cells of all the essential tissues of the metazoan body, when so placed separately as to be provided with the appropriate food in the right amount and to have the deleterious metabolic wastes promptly removed, are potentially immortal. The cells so cultured do not become highly differentiated so long as they grow out of association with other tissue cells. It, therefore, appears that differentiation of tissues along special lines for special purposes is conditioned by association with other cells, and inevitably leads to conditions which result in senescence and, finally, death.

Study of the growth relations of fishes and other animals by Bidder shows that a water-borne animal may continue to grow almost indefinitely, but that swiftly moving land animals must maintain a definite relation between body weight

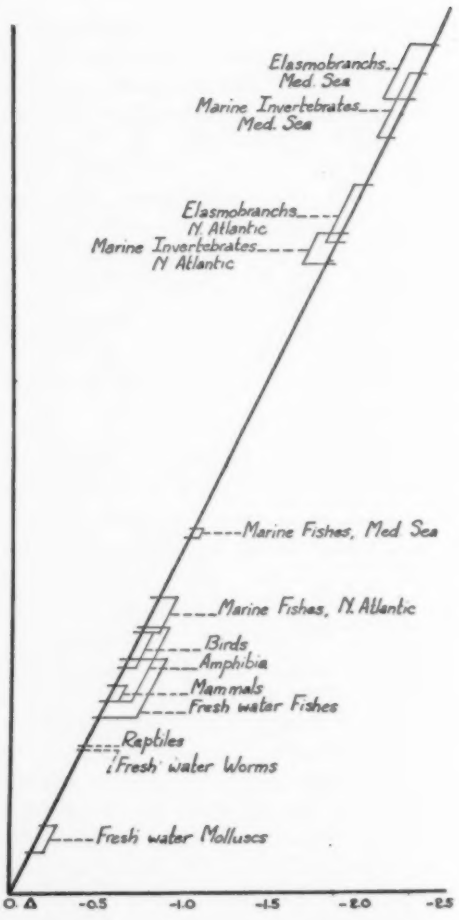


FIG. 1. A CHART INDICATING THE SALT CONTENT OF THE BLOODS OF LARGE GROUPS OF ANIMALS AS DETERMINED BY THE FREEZING POINT METHOD. Abscissae indicate freezing points; ordinates indicate durations of time during which the salt content of the ocean has been increasing from a minimum to the values now found in the Atlantic and in the Mediterranean Sea. The suggestion is made that the grouping of fresh-water fishes, mammals, amphibia, and birds may have some relation to the concentration of salts in the sea when the ancestors of these animal groups left their marine habitat. The diagonal may represent the rather steady and continuous increase in the salt concentration of the sea water with the passage of time. Rogers, "Text Book of Comparative Physiology," Copyright, 1927, by the McGraw-Hill Book Company, Inc. (Reproduced here by permission.)

and the cross-sectional areas of their bones and muscles. Before puberty, men and plaice show additions to weight, in equal intervals of time, in geometrical progression. After sexual maturity additions in weight occur in arithmetical progression. In the fish the annual increment remains positive; in the man the difference in weight actually becomes negative, and from twenty-eight years of age on there is a constant net loss of weight of protein, amounting annually to about 0.8 per cent. of the weight at twenty-eight years. The mechanism of the adult body is set after puberty to a certain annual balance of profit and loss: for aquatic animals this may be a positive increment and life may be eternal; for terrestrial animals the length of life depends on the nearness to equality of profit and loss. An annual increment, however small, will eventually result in death from gigantism: it is not improbable that this has been, and possibly is now, the form of death in some quadrupeds. A negative annual increment, however, determines a date at which all capital resources will disappear. We die, therefore, as an alternative to becoming giants.

From the statements made in this brief summary it will be seen that evidences of animal evolution and of animal relationship may be secured from a variety of lines of physiological inquiry. These evidences seem as worthy of credence as those coming from paleontology, comparative anatomy or embryology. There are doubtless other similar lines of inquiry which have a bearing upon the general problem, and there can be no question as to the need for much further knowledge of the facts along the lines which have been mentioned.

PHOTOELECTRICITY[1]

By Sir WILLIAM BRAGG, K.B.E., D.Sc., F.R.S., M.R.I.
FULLERIAN PROFESSOR OF CHEMISTRY, ROYAL INSTITUTION OF GREAT BRITAIN

THE relations between light and electricity are of unending interest. More than fifty years ago the experiments of Faraday and the calculations of Maxwell culminated in the splendid electromagnetic theory of light, on which subsequent research has built largely and firmly.

Even in the early days of the theory there was known to exist a peculiar and special relation to which the name of photoelectricity was given. The theory gave no ready explanation of it. Light falling upon a metal plate could cause the plate to become positively charged; ultra-violet behaved better in this respect than visible light. When subsequently the electron was recognized and defined, it became clear that the photoelectric effect could be explained as due to an emission of electrons from the metal under the influence of the light, and various suggestions were offered as to the nature of the mechanism. It was clear that the absorption of energy from the electromagnetic waves of light was replaced by the energy of electrons in motion, though at that time there was no obvious relation between the quantities of energy in the two forms. As time went on it was realized that this particular transformation was not an isolated effect; it was but an instance of one of the most important and widespread processes of physics. It was to be observed not only in the case of light but of X-rays and γ-rays also; and indeed in their case it was infinitely plainer and more accessible to experiment. But it also became continually clearer that the process was not to be explained in any simple fashion, if at all, by the original electromagnetic theory of light, or by any natural development of that theory.

At the same time a number of other physical phenomena, and especially the relation between the quality of the radiation from a hot body, and the temperature of that body, showed also that the older theories were unable to account for the facts. They could be accounted for by supposing that heat could be radiated or absorbed only in parcels of definite size, no fractions being allowed. If such an idea might be reconciled with the undulatory theory, *i.e.*, of electromagnetic waves, at least it was not contained therein. This was the beginning of the quantum period.

In 1905 Einstein published a pioneer paper in the *Annalen der Physik* in which the quantum was given an identity even more definite than that which Planck had assigned to it in his studies on heat radiation. Light was to be regarded not as a uniform train of spherical waves but as a flight of "quanta," corpuscles of some form to be better known on closer acquaintance. By reverting to a corpuscular theory of light he was able to connect the new facts, which were in such apparent discord with the undulatory theory. In doing so he, of course, shut his eyes for the moment to the marvelous and most successful development of the latter theory to the explanation of such phenomena as reflection, refraction and diffraction. He would simply find a new theory to connect the new facts; this done, the new and old theories could be brought

[1] Address before the Royal Institution of Great Britain.

together in the hope of welding them together. As he announced in the title of his paper, he was going to take the heuristic point of view.

Since 1905 new discoveries of first-class importance have been made, but still there is no simple answer to the old question. The most recent and, so it is said, the most successful solution is given by the hypothesis of so-called wave-mechanics, due largely to M. L. de Broglie and Dr. E. Schrödinger. It is now the subject of eager discussion in mathematical and physical circles.

The managers of the Royal Institution have invited Dr. Schrödinger to give a short course of lectures on wave-mechanics at the Royal Institution, and have been gratified by the acceptance of their invitation. It has been arranged that the lectures shall be given on March 5, 7, 12 and 14. Also Professor Whittaker, of Edinburgh, has accepted an invitation to give the Friday evening discourse on March 16, on which occasion he will try to summarize for the benefit of our members the features of the new position.

My discourse this evening is meant to be of a preparatory nature. I would like to set out the observed facts for which it is so difficult to find a common explanation, so far as it is possible to do so in the short time at my disposal. I can not, of course, tell the whole story; I can only describe a few of the most important details of it.

Einstein begins his 1905 paper by pointing out, as a curious fact, that matter is now looked on as a collection of discrete particles, while light, which resembles matter in being one of the great phenomena, is treated as a continuous distribution in the space over which it passes; and he suggests that it would be well to consider a discrete view of light also. He then enumerates certain experimental results which would be in obvious agreement with the new theory, though not with the old. Most of them are beyond our capacity to consider in the short hour of this discourse; but two of them may well be considered by us as amply sufficient to illustrate our argument and easily demonstrable even on the lecture table.

The first of them is summed up in what is called Stokes's Law of fluorescence. When light falls upon a fluorescent substance the fluorescent light evoked is always of longer wave-lengths than the exciting light; in other words, its frequency is less. Now, if a corpuscular theory of light is to be adopted, wave motion of a given frequency must be replaced by some characteristic of the corpuscle; and it appears that the two, and only two, characteristics of a wave motion, namely, frequency and intensity, are to be replaced respectively by individual energy and numbers of corpuscles. This has to be done in order to explain both the results we are considering and a number that we are not. On the corpuscular theory a beam of violet light is a flight of corpuscles each having a certain energy which is proportional to the frequency of the light. A beam of green light is a flight of corpuscles each having a certain energy less than the other, because the frequency is less. It is easy to imagine that the flight of more energetic corpuscles may be degenerated by impact with the body into a flight of less energetic corpuscles. But it is very difficult to see how undulations of one wave-length can on meeting material substances be converted into undulations of a different wave-length.

A still more striking argument is found in the photoelectric effect itself. Lenard had shown three years before that when the electrons came out of the solid body under the influence of the light their individual energy did not depend upon the intensity of the light, but upon its frequency; the intensity affected only their number. This was an extra-

ordinary result. It might have been thought that the more energetic or violent the waves of light which caused the emission of electrons, the greater the velocity with which the electrons would start on their way. And as to the influence of frequency, it would be difficult to say how it would go; though one would not readily expect it to be the sole arbiter of the velocity. But if light was corpuscular the process, though still unexplained in detail, ceased to look so strange. Each corpuscle acting independently would cause the emission of an electron. The intensity of the beam of light would depend on the number of corpuscles it contained, and their impact on the body would cause a proportionately large emission of electrons, making the photoelectric effect. And light of high frequency would on the corpuscular view consist of swiftly moving corpuscles, which, having large energy, would cause the emission of relatively swift electrons. The whole phenomenon, by its character and definiteness, spoke entirely for the corpuscular theory. Einstein explains the point perfectly clearly in his famous paper of 1905, and suggests that, if he is right, far more careful quantitative observations would be justified, as they would give an authoritative verdict on the validity of the theory which he proposed. He suggests that workers might bear his views in mind when proceeding with their experiments.

Einstein's theory must have been discussed exhaustively; but, so far as I know, no allusion to it, or criticism, is to be found in the principal journals of physics for some years afterwards. In fact, it was not until seven years later that Richardson and K. T. Compton carried out the careful measurements which Einstein suggested.

The results were in absolute accordance with the exact rules which he had supposed would govern the photoelectric effect, having based them on the less well-defined information which was available when he first wrote.

I must now be permitted to describe some experiments which I carried out in Australia twenty years ago in conjunction with several helpers, in particular R. Kleeman and J. P. V. Madsen. I had been working out certain laws which governed the passage through matter of the X-rays emitted by radium; and I had tried to carry over the information so obtained to an investigation of the behavior of the β- and γ-rays. Now when γ-rays fall upon a substance they excite β-rays, which are electrons in very swift motion. In fact, the analogy with the photoelectric effect is exact, for the rays as we now know are a form of light of very high frequency. The characteristic features of the photoelectric effect appear here also and greatly emphasized. The swift β-rays are far easier to detect and to examine than the electrons set in motion by light. The parallelism was not then so obvious as it is now, and for my own part I could not then believe in its existence. Our experiments fitted in perfectly with a corpuscular hypothesis of the nature of the γ-rays; and I supposed that the undulatory theory of light was unshakable. I should, of course, have thought otherwise if I had been aware of Einstein's paper, to which I have already referred; but it is easy to miss a single reference when one is in a very isolated laboratory, and, as I said before, there are few if any allusions to the paper in the current literature of the years immediately following its appearance.

Our experiments in 1907 and 1908, coupled with others to which we were able to refer, led us to the following conclusions:

(1) When β-rays or γ-rays were incident on matter the energy of any resulting secondary radiations of any kind, β or γ, came from the rays. There was no

"induced" radioactivity; no case of the energy of an atom being tapped. The adoption of this hypothesis simplified all further considerations of the phenomena.

(2) The so-called hard or very penetrating γ-rays produced swift and penetrating β-rays; soft γ-rays produced slow β-rays.

(3) The penetrating power or quality of the β-rays, produced by the action of γ-rays, depended only on the quality of the γ-rays, not upon the intensity of the γ-rays nor upon the nature of the substance in which the transformation of energy took place; it was practically the same as that of the β-rays issuing from the radium itself.

(4) The β-rays produced in any substance by the action of the γ-rays moved at the outset in the original direction of the γ-radiation.

The last statement is capable of simple demonstration in the lecture room. The necessary apparatus is shown in the figure, which is taken from a paper by Madsen and myself. The radium is buried in a mass of lead, at the foot of a conical pit. Both β- and γ-rays issue from the mouth of the cone, but the former are turned aside by a strong magnet. The γ-rays pass on alone into an ionization chamber. The beam of γ-rays is not quite free of β-rays because the latter are aroused even in the air through which the γ-rays pass on their way to the chamber, but the magnet has removed most of them. If now a carbon plate be placed in the path of the γ-rays as they enter the chamber there is a large increase in the ionization current; the γ-rays as they pass through the block on their way generate β-rays, which cause the observed effect. But if the carbon plate be placed on the far side of the chamber so that the γ-rays strike it on the way out, there is a relatively small increase in the current. Yet the rays must have generated β-rays to very nearly the same amount in both positions of the plate; and the dissymmetry between the intensities of the "emergence and incidence" β-rays (the one is ten times that of the other) tells us that the β-rays are largely thrown forward as they are produced. In fact, from what is otherwise known of the behavior of β-rays on their way through matter, we might suppose that the β-rays were thrown forward exactly in the line of the γ-rays, for the substance of the carbon screen would turn back a certain proportion of the rays, and the incidence radiation could be accounted for in this way. Nevertheless, we know now, from more accurate work which we shall presently consider, the β-rays are not so closely tied down to the forward movement, and when the γ-rays are soft and the β-rays relatively slow the difference between emergence and incidence is less marked. The experimental difference is also much less when the carbon plate is replaced by screens of higher atomic weight.

Thus again we have those characteristics which led Einstein to suggest a corpuscular theory of light in order to account for them when manifested in the photoelectric effect. Here they are displayed in an immensely enhanced degree. Consider the γ-ray as a spherical wave weakening as it spreads away from its source. It arrives at a certain atom; a β-ray springs out of the atom with an energy which is just the same, no matter how intense are the γ-rays, or how the intensity has faded with distance. Moreover, it possesses a forward momentum which could not possibly, by millions of times, be given to it by the wave, although a wave can impart a certain momentum to an encountered obstacle.

These questions of energy and momentum are even more obviously displayed in the case of the X-rays and the electrons which are concerned both in their production and their absorption. In the X-ray bulb the electron is driven

with a certain speed against the anticathode, the X-ray which is thereby excited passes away and, falling on some substance, it may be far or near, sets in motion an electron which has a speed comparable with, sometimes nearly equal to, that of the original. Here again is the same kind of transformation of energy, which is simply pictured as carried, unchanging on its way, either by the β electron or the corpuscle of the γ-ray.

I may say, I think, that in these experiments we were, though unwittingly, carrying out Einstein's suggestion that the corpuscular hypothesis deserved careful exploration; and the results were in entire agreement with his hypothesis. It was true, however, that I thought of the X-ray and γ-ray problems as distinct from that of light; and I ventured prematurely to give form to the corpuscle as a neutron, an electron compensated as to its charge by the addition of a neutralizing amount of positive.

In 1910 and 1911 C. T. R. Wilson published accounts of his experiments with his fog chamber. These rendered obvious to the eye those tracks of the various rays through a gas which we had endeavored to map out by more indirect means, and entirely confirmed the conclusions that had been reached. I may perhaps be allowed to illustrate this in the special case of the α-rays, though they do not fall within the limits of our subject. In Fig. 1 is shown a set of tracks of α-rays drawn so as to be in accord in the first place with the work done in Adelaide; and also to agree with the more recent experiments on their scattering performed by Rutherford and Geiger. Fig. 2 is from a photograph of one of the well-known early achievements of Wilson. It may be a matter of interest that on a certain occasion in the Cavendish Laboratory at Cambridge we showed them to each other for the first time.

Wilson's photographs of the tracks of X-rays, β-rays and cathode rays, placed the argument on a different plane; and their beautiful detail opened up the way to quantitative measurements which had seemed impossible. It was now obvious

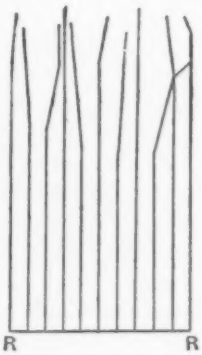


FIG. 1. SUGGESTED FORMS OF THE PATHS OF α PARTICLES PROJECTED UPWARDS FROM RADIUM AT R R.

FIG. 2. FROM PHOTOGRAPH OF α-RAY TRACKS BY C. T. R. WILSON.
Courtesy of Macmillan & Co., Ltd.

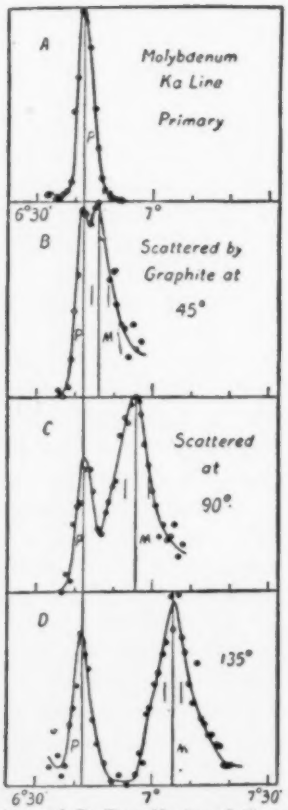
to the eye that X-rays and γ-rays did not of themselves ionize a gas, but set in motion electrons which did so. The lengths of the tracks of these electrons in a gas could be measured, and their initial

velocities be calculated therefrom; their directions of ejection could also be observed. All fitted in perfectly with the quantum theory of the X- and γ-rays, even when refinements could now be studied, as, for example, the differences in velocities of ejection which were to be expected on Bohr's theory of stationary state.

In 1913 the discovery of the diffraction of X-rays by the crystal opened up a new point of view, and once more changed, or rather enlarged, the aspect of the question. It now appeared that X-rays and γ-rays in these effects behaved like long trains of spreading waves, and no clear picture of what happened could be obtained in any other way. In this matter the corpuscular theory was at sea. Even the old single-pulse theory was in no better case, because it did not provide the regular succession of similar waves which was required to account for the crystal effect. The new discovery consolidated the position, linking together light, X-rays and γ-rays as one phenomenon; if they were regarded from the point of view of the undulatory theory they were all waves which differed only in frequency. If any other point of view was taken, that of a corpuscular theory for example, the equivalence must be expressed in some equally effective fashion. On the other hand, the simplification emphasized the difficulties of the position, since it left no escape from the necessity of finding a theory which could with equal ease and effectiveness express itself in terms either of waves or of corpuscular projectiles. Whether or no this has yet been done by any of the theories now in being is indeed the question of the day; our judgment will, I hope, be assisted by the lectures that are to follow.

Meanwhile matters have by no means remained stationary since the powers of X-ray and crystal analysis have been put into our hands. With the aid of the X-ray spectrometer we can measure with extreme accuracy the wave-lengths and frequencies of X-rays. When X-rays are incident upon a substance they are to some extent scattered as such, just as a ray of light is scattered in passing through a dusty atmosphere. This is apart from the photoelectric effect, namely the production of swift-moving electrons at the expense of the energy of part of some of the incident rays. The X-rays are scattered by the atoms and electrons; the light being of coarser wave-lengths is scattered by the coarser particles of dust. Now when γ-rays, which are very fine X-rays, are scattered it has often been remarked that the scattered rays are somewhat softer than the originals. A. H. Compton used the spectrometer to examine if possible this softening, if X-rays could show it. They not only did so, but the experiments showed also a real change of wave-length varying according to circumstances, and obeying simple rules. It appeared, in fact, that there was a definite small change in wave-length, which depended on the angle of scattering, but not on the original wave-length nor on the nature of the scattering material. Figs. 3 and 4, taken from Compton's new book "X-Rays and Electrons,"[2] show the effect very clearly. They represent the results of the spectrometer observations; in each curve one hump is due to rays that have not been altered by scattering, and have preserved the same frequency as the original beam. A second hump is the evidence of the "modified" scattering; the relative amounts of the two vary with the scattering substance. Every material returns something of both kinds; but the lighter the atom the more intense is the modified in comparison with the unmodi-

[2] A. H. Compton, "X-Rays and Electrons." New York, D. Van Nostrand Co., 1926.



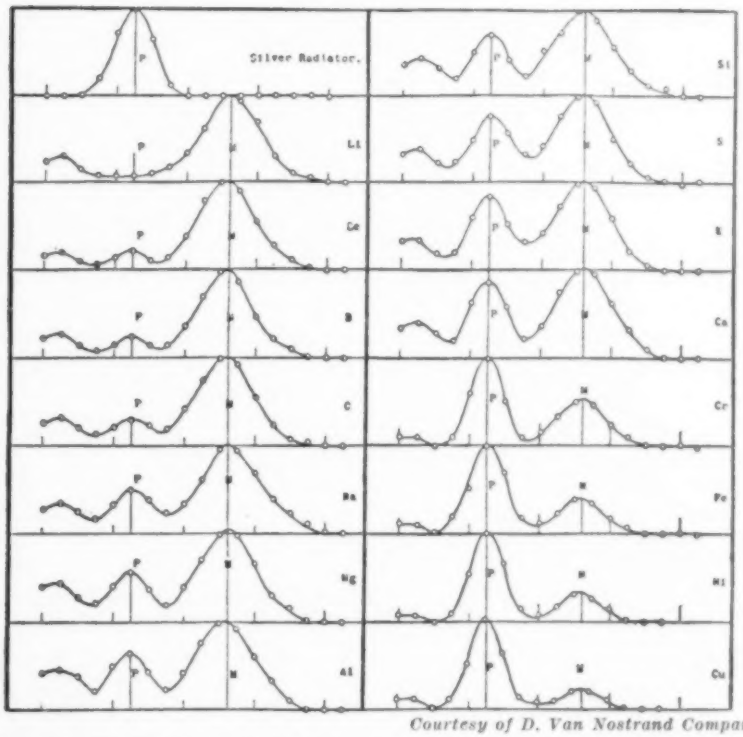
Courtesy of D. Van Nostrand Company, Inc.

FIG. 3. ABSCISSAE REPRESENT ANGLE OF SCATTERING AND ORDINATES REPRESENTING INTENSITY. THE HUMP ON THE LEFT OF EACH FIGURE REPRESENTS THE INTENSITY OF THE SCATTERED RADIATION, WHICH HAS THE SAME WAVE-LENGTH AS THE PRIMARY BEAM. THE HUMP ON THE RIGHT MARKED M REPRESENTS THE INTENSITY OF THE MODIFIED PORTION OF THE SCATTERED RADIATION. THIS FIGURE SHOWS HOW THE EFFECT DEPENDS ON THE ANGLE OF SCATTERING.

fied; at the same time, as already said, the change of wave-length is constant from substance to substance. The phenomenon is a little like that of fluorescence, but the likeness is only on the surface. But this is true of both, that the undulatory theory does not suggest a simple explanation in either case. I ought to say that Professor Raman, of Calcutta, has just announced in *Nature* that he is able to explain the Compton effect on classical lines, and promises to give his new theory in full.

On the other hand, the corpuscular theory gives at once an explanation which is relatively simple, and allows quantitative deductions to be made which are in entire agreement with the facts. If a corpuscle or "photon," to use the term which has lately been suggested, comes into collision with an electron, as it can do in traversing any material, it is possible to work out the consequences as if for an impact between two billiard balls, assuming only that both photon and electron have momentum and energy, the quantities being reckoned according to rules already established. The result is that the photon goes off with somewhat diminished energy; it has lost "frequency," and the calculated loss is exactly that which is shown in Fig. 3 as the result of experiment. Moreover, the electron ought to start off with a certain amount of energy, and when Wilson's photographs are examined the predicted tracks are found on them. Thus the spectrometer, which is based on an undulatory theory of X-rays, has established facts which are in accord with the corpuscular theory.

When we see in this way that radiation, which has always been thought of as undulatory, can on occasion display corpuscular properties, we are prompted to ask whether moving electrons—β-rays, cathode rays, and so on—which we have always considered as corpuscular, may not behave sometimes like waves? The answer appears to be in the affirmative. In America Davisson and Germor have recently described most remarkable experiments in which moving electrons are reflected by crystals in a manner bearing an obvious, though diffuse, resemblance to the now well-known reflection of X-rays, and the latter is always ex-



Courtesy of D. Van Nostrand Company, Inc.

FIG. 4. THE SCATTERING SUBSTANCE IS MODIFIED, AND IT IS TO BE OBSERVED THAT THE LESS THE ATOMIC WEIGHT OF THIS SUBSTANCE THE GREATER IS THE RELATIVE MAGNITUDE OF THE MODIFIED PORTION.

plained on the basis of an undulatory theory. More recently still, Professor G. P. Thomson, of Aberdeen University, has shown that when electrons are shot through a very thin film of metal, halos are formed upon a photographic plate on the other side of the metal, which may be explained qualitatively and quantitatively if the electrons act as waves in passing through the minute crystalline particles of the metal film. Professor Thomson has promised, I am glad to say, to give us an account of this work in a Friday evening discourse after Easter, and this will follow naturally on the lectures by Dr. Schrödinger and Professor Whittaker.

I hope that this brief sketch of the present position will give some idea of its extraordinary and fascinating difficulties. Perhaps the details of the picture are sorting themselves out, and we shall see before long where we have failed to see some important point which was required for the complete resolution. When the picture is finally clear there will no doubt be atoms in it, electrons, wave motions, energies, momenta, and so on. But have we got them all rightly joined? Perhaps wave motion belongs to more than the photon, or to something else than the photon? We can only wait.

LOGIC OF GRAVITATION

By Dr. HENRY LANZ

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In the opening chapter of "An Introduction to Celestial Mechanics" Professor F. R. Moulton expresses a regret that owing to the difficulty and complexity of metaphysical speculations science is not in a position to enter into the discussion of questions pertaining to the "origin" of the laws and principles involved. "It is not to be understood," he adds, "that such investigations are not of value . . . In order to obtain a complete understanding of the character of the conclusions it would be necessary to make a philosophical discussion of the reality of the elements and of the origin and character of the principles and laws." This is a vast design involving the whole body of logic. In partial fulfilment of it the present paper is conceived.

Modality of Gravitation

Every law of nature is an assemblage of logical elements in a specific correlation with each other. Among various forms of interrelation of those elements there is one which the logicians of the old school were in the habit of calling modality. Modality is a logical category that indicates the degree of certainty associated with a given judgment. A judgment — and every law of nature is a judgment—may be pronounced problematically as mere conjecture, or stated empirically as a fact, or on the basis of certain assumptions established as a necessity. Thus modality is commonly regarded as having three forms: hypothesis, facticity and necessity. The only form of necessity recognized by science is mathematical necessity.

Now we are in position to formulate our problem more specifically. From the vast terrain of inquiry suggested by Professor Moulton we select a small, but highly representative and instructive segment. We limit our task at present to the logical analysis of the law of gravitation, and more specifically to the analysis of modality of that law in the form in which it was originally formulated by Newton.

Is the law of gravitation a mere hypothesis invented to suit certain facts obtained by observation? Or does it possess a certain degree of mathematical necessity which can be formulated apart from and prior to any astronomical observation or physical experiment? If it does, in how far is it mathematically "necessary" and in how far does it depend on "facts"? It is commonly believed that the law of gravitation is a hypothesis with a very high degree of verification by facts. Is this current interpretation of the modality of the law correct? "Hypothesis," we read in an authoritative treatise on logic,[1] "is a name that may be applied to any conception by which the mind establishes relations between data of testimony . . . so long as that conception is one among alternative possibilities, and is not referred to reality as a fact." Is the law of gravitation "referred to reality as a fact" or does it allow "alternative possibilities"? We shall begin our investigation with the law of areas.

Law of Areas

On the assumption of central acceleration is it possible for a body not to describe equal areas in equal times? Let us briefly recapitulate Newton's argu-

[1] B. Bosanquet, "Logic," 2, 155.

ment on this important point. Suppose a body is subject to a central force, whatever its nature may be. Let us regard the action of the force as represented by a series of infinitesimal blows or pushes. Suppose that at the time instant t_0 the body moves in the direction of the line AC (Fig. 1), and that upon arriving at B at the end of an infinitesimal interval of time t_0t_1 it is acted upon by an instantaneous force acting along the line OB. During the next increment of time $t_1t_2 = t_0t_1$ under the effect of two velocities the body will be sent to the point E, CE = BD being the velocity acquired at the end of the preceding interval of time. The triangles OEB and OCB having the base OB and equal altitudes EM and CL have equal areas. For similar reason the area of the triangle BOC is equal to that of BOA. Therefore $\triangle EOB = \triangle BOA$.

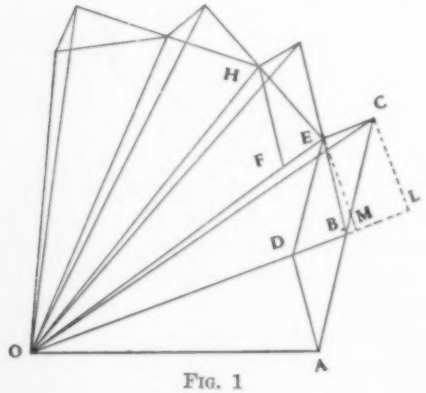

FIG. 1

If the process be repeated, during the next equal interval of time the lines OE and OH joining O to the positions occupied by the body at the instants t_2, t_3 will form triangles of equal areas without regard to whether the lines EF and BD are equal or not, *i.e.*, whether the acceleration is constant or not. Since the duration of our time increments may be diminished indefinitely and since in any given interval of time equal number of equal triangles will always be described by the line joining the body to the center O, by the process of integration we are entitled to conclude that no matter how the body moves around O the areas which it describes by radii drawn to an immovable center lie in the same immovable plane and are proportional to the times in which they are described.[2]

There is no alternative in this argument. On the assumption of central acceleration no physical body can move in any other way. The equality of areas traversed by the radius vector in equal times is, therefore, not a hypothesis, but a mathematical fact deduced from a given assumption. Whether the assumption is "true" or not does not in the least affect the value of the deduction. In fact, our deduction does not show that there is any physical body in the universe which moves exclusively under the effect of central acceleration. It only shows that if there were any such body, the law of areas would be invariably true of its motion. No experimental evidence would add anything to the conclusiveness of the argument. Newton makes no reference to Kepler's observational data; they do not appear among the premises of his argument. In fact, his intention is to explain those observational data by reference to the law, and not the latter by reference to the observed facts. If Newton's assumption is true it follows that Kepler could not possibly observe Mars performing any other movements than those which he actually observed.

This, however, does not in the least diminish the value of observation. Mathematical analysis never gives us any clue as to reality of the objects discussed. It only shows that if such and such a proposition is true of anything, some other proposition must be true of that thing. If there is in nature such

[2] Newton, "Principia mathematica philosophiae naturalis," Book 1, Prop. 1.

a thing as a Euclidian triangle, the sum of its angles must be equal to 180°. If there is any body that moves under the effect of a central force, its radius vector must describe equal areas in equal times. Newton proves that the converse is also true (B. 1, Prop. 2), *i.e.*, if there is a body that follows the law of areas, it must be moving under the effect of a central force. Yet the mathematical analysis can not prove that any such body exists. Here the observation comes in. Kepler observed that Mars does actually move in such a way that the radius vector joining it to the sun covers equal areas in equal times. The conclusion is that the planet has a central acceleration towards the sun.

Galilei's Achievements

It is furthermore not difficult to show that under the assumption of a constant central acceleration all Galilei's formulae for falling bodies follow mathematically from that single assumption. For, since the acceleration is constant, we have

$$\frac{d^2s}{dt^2} = k.$$

After two successive integrations it becomes:

$$s = f(t) = {}^1/_2kt^2 + C,$$

i.e., acceleration can be constant only on the condition that the original function (the space traversed) is proportional to the square of the time, which is the basis of all Galilei's deductions.

Next to Kepler's three laws of planetary motion, Galilei's law of the falling bodies constitutes another historical premise of Newton's work. We see again that this premise involves no hypothetical elements. It is not a happy guess that should be first verified by a laboratory experiment. It is mathematically necessary. If we assume that heavy bodies fall under the effect of a force that remains constant, they can not possibly fall according to any other law —not because we observe them in that condition, but because it is mathematically impossible. To say that a body moves under the effect of a constant force is the same as to say that the space traversed by it is proportional to the square of the time.

Newton's Law of Gravitation

We have seen that Galilei's laws of falling bodies follow mathematically from the assumption of a constant gravitational force. It is natural to assume that the force remains constant on the surface of the earth as long as we believe that earth is a perfect sphere. But what will happen to the force as we move away from the center of gravity? Will the force vary with the distance? And if it will, according to what law? That was the problem that Newton faced.

And here we clearly perceive at once that the concept of central force alone is not sufficient to derive the law of gravitation. It does not give us any clue as to how the intensity of force will change with respect to the distance. In each particular case the nature of the path depends on the law of the force. If we know that the body moves in a spiral, then—assuming that it moves under the effect of a central force—we can analytically find that the intensity of that force changes in the reverse proportion to the cube of the distance (B. 1, Prop. 9). If we know that the body moves in an ellipse, then—assuming that it moves under the effect of a force directed toward the *center* of the ellipse—we shall find that the force changes *directly* as the distance. Suppose that we never find such conditions in nature. That would have no effect upon the mathematical validity of our results. In fact we never find those conditions fulfilled, at least not in celestial mechanics; the controlling body of a gravitational system is never located in the center of any elliptical orbit described by any of its satellites. It is always found to be located in the *focus* of the ellipse.

Thus it is impossible to derive the law of gravitation mathematically from the assumption of central force, as it was possible with regard to the law of areas. In this latter case we needed no support from any observation whatsoever. Every moving body controlled by a central force must comply with the law of areas, no matter what the law of the force may be. In other words, it is independent of the nature of acceleration. But the law of gravitation is a specific law. We can not derive it from the generic concept of central force. There are many other laws mathematically possible. Here is, therefore, a point where observation substantially affects our celestial mechanics. In order that we could find the law of force, the path of a body moving under the effect of that force must be given. And when it is given, the law of force follows mathematically from it. It is, therefore, not a matter of mathematical necessity, but merely a matter of fact that the force of gravity is inversely proportional to the square of the distance.

Therefore, the assumption of central force as applied to the observed paths of the celestial bodies is logically sufficient to produce the law of gravitation. No further hypothesis as to the nature of the force is needed. The assumption of central force is the only hypothesis that Newton makes. And with it stands or falls his whole fabric. If we assume that planets are driven by forces—which is by no means self-evident, as they may move in similarly curved lines owing to the nature of the time-space—if we assume that they are driven by forces in a Euclidian space, then the form of their orbits mathematically determines the law of the force.

Thus we see that the common interpretation of the law of gravitation as a hypothesis that "admirably fits the facts" is logically incorrect. It does not merely fit the facts of observation, but it is nothing else than the mathematical expression of those facts. It is not a guess that for some unknown reason is found to be universally correct. It is also erroneously called a deduction from observations. For Newton made his deductions independently of observations and concluded that wherever the conditions of his analysis are fulfilled in experience the results must also hold true. "In mathematics," he writes, "we are to investigate the quantities of forces, with their proportions consequent upon any conditions supposed; then, when we enter upon physics, we compare those proportions with the phenomena of nature, that we may know what conditions of those forces answer to several kinds of attractive bodies. And this preparation being made, we argue more safely concerning the physical species, causes and proportions of the forces."[3]

To say that intensity of gravitational force is inversely proportional to the square of the distance is merely another way of saying that celestial bodies in the immediate neighborhood of each other move with respect to each other in conic sections. With such paths given by observation there could not be any alternative as to the law of the force controlling them. Planets could not possibly move in elliptical orbits, and at the same time obey some other law. If we had suddenly discovered a body that moved around the sun on a spiral, we would be obliged to conclude, not that the law of gravitation is invalid, but that the sun acts with regard to that body, not as a gravitational center, but as a center of some unknown force whose intensity varies as the cube of the distance. But there again could be no alternative. The modality of the law could not be interpreted as a hypothesis.

Einstein's Law

Yet it may be objected that Einstein's law presents an alternative. The solution of Einstein's equations of the gravi-

[3] "Principia," Book 1, Prop. 69, Scholium.

tational field leads to the conclusion that in the neighborhood of a material particle our space-time is non-Euclidian.[4] That shows that our physical space-time is not everywhere flat, but is curved within electromagnetic and gravitational fields. In such space particles will move in curved lines independently of any attractive forces. That is to say, the assumption of space-time curvature is sufficient to account for any material particle's deviation from Euclidian straight line. Moving solely under the effect of inertia every material body in the neighborhood of another material body will follow a curved path. The curvature in this case, however, will not exactly coincide with that which is prescribed by Newton's law. The deviation will be extremely small, yet the more appreciable the nearer we come to the center. Such deviation was actually observed in the motion of Mercury, whose perihelion was found constantly displaced in a manner unaccountable on the basis of Newton's law.

Now, does it prove that Newton's law of universal gravitation is no longer valid? But what does it epistemologically mean, "no longer valid"? If it means that conditions formerly assumed to be real are no longer observed to be real, then the law is not strictly valid, even though the discrepancy is very small. Yet we can always hope to account for the disagreement considering a possibility of some disturbing factor of which we are at present unaware. The discrepancy in the case of Mercury is in fact so small and so unique that to declare the whole system invalid just on its account would be quite premature. If, on the other hand, "not valid" means mathematically or logically inconsistent, then, of course, Newton's law is, and always will be, just as secure as it ever was before. No amount of observational evidence or advanced mathematical analysis can destroy its validity in this sense. For as long as we remain within the sphere of Newton's fundamental assumptions, *i.e.*, as long as we believe in force, his deductions are inviolable.

And yet there is a sense in which Newton's law may be regarded as no longer valid. Euclid's assumptions are neither more nor less reasonable than those of Riemann or Lobachefsky. They are purely mathematical postulates which can be independently and arbitrarily pursued till their remotest consequences are reached. But Newton's assumptions are not purely mathematical. They involve a factor which determines acceleration, and is not itself identical with acceleration. "If any force," Newton says, "generates a motion, a double force will generate double the motion, a triple force triple the motion." This is evidently an assumption that can never be verified by observation, for force is inaccessible for observation except through the motion which is generated or determined by it. If force increased in geometrical progression, while the quantity of motion gained only arithmetically, no one would be able to discover it. The truth of the assumption, therefore, lies solely in our inability to verify it. Such force is a mere farce. It is a remnant of the animistic, theological thinking.[5]

[4] A. S. Eddington, "Space, Time and Gravitation," p. 97.

[5] A highly satirical caricature on the nature of this assumption we find in Eddington's "Space, Time and Gravitation." He presents the situation in form of a fairy tale: "A race of flat-fish once lived in an ocean in which there were only two dimensions. It was noticed that in general fishes swam in straight lines unless there was something obviously interfering with their free courses. This seemed a very natural behavior. But there was a certain region where all the fish seemed to be bewitched. . . . By-and-by a theory was proposed; it was said that the fishes were attracted towards a particularly large fish—a sun-fish—which was lying asleep in the middle of the region; and that was what caused the deviation of their paths. The theory might not have sounded particularly plausible at first. . . . Some fish

Einstein, following Minkowski, instead of assuming a force as a factor generating acceleration of gravity, proposed to assume a different geometry in the neighborhood of material bodies. On this assumption gravitational acceleration becomes indistinguishable from mere inertia. A planet, for instance, obeying no other law than that of inertia, acquires central acceleration towards the sun, not because the latter attracts it in some mysterious way through the distance, but simply and solely because the nature of space-time makes it appear to be moving under the effect of an attractive force directed towards the origin. Thus was destroyed the only hypothesis that Newton had ever made. Modality of gravitation was proven to be free from any hypothetical elements. In a letter to Cotes Newton writes: "Whatever is not deduced from the phenomena is to be called hypothesis; and hypotheses, whether metaphysical or physical, . . . have no place in experimental philosophy. In this philosophy, particular propositions are inferred from the phenomena, and afterward rendered general by induction." Of all the logical elements that constituted the law of gravitation force was the only one that was "not deduced from the phenomena." And it is precisely this element that is now discarded.

HYPON—A HYPOTHETICAL ELEMENT AND A POSSIBLE SOURCE OF STELLAR ENERGY

By W. S. ANDREWS

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THE source of the energy that is continuously radiated into space chiefly in the form of heat and light by our sun and other stars is an unsettled problem although many ingenious theories have been devised to account for it. The evolution of temporary stars or "novas" is also still enshrouded in mystery. It was formerly believed that a nova was a cosmic conflagration caused by the collision of two heavenly bodies, but modern study has ascribed its appearance to the actual explosion of a star from within itself, like a gigantic bombshell. A few facts—and fancies—relating to these matters are here presented to the reader.

It is well known that the atomic numbers of six gases—helium 2, neon 10, argon 18, krypton 36, xenon 54 and radon 86—agree with the first six terms of the following simple number series: $2(1^2 + 2^2 + 2^2 + 3^2 + 3^2 + 4^2 + 4^2 + \ldots)$. That is to say:

$2(1^2) = 2$, helium's number
$2(1^2+2^2) = 10$, neon's number
$2(1^2+2^2+2^2) = 18$, argon's number
$2(1^2+2^2+2^2+3^2) = 36$, krypton's number
$2(1^2+2^2+2^2+3^2+3^2) = 54$, xenon's number
$2(1^2+2^2+2^2+3^2+3^2+4^2) = 86$, radon's number

This remarkable agreement in numbers, up to and including the sixth term of the number series, invites attention to the seventh term, which is 118 $[2(1^2 + 2^2 + 2^2 + 3^2 + 3^2 + 4^2 + 4^2) = 118]$. There are, however, only ninety-two known chemical elements, and uranium being the heaviest is atomic number 92. It is, therefore, plain that 118 can not be counted as an atomic number unless, indeed, twenty-six new and hypothetical elements, all heavier than uranium, are arbitrarily added to the regular stand-

grumbled that they did not see how there could be such an influence at a distance; but it was generally agreed that the influence was communicated through the ocean and might be better understood when more was known about the nature of water."

ard list. This idea may naturally be deemed too wild for serious consideration, but nevertheless it is proposed to offer some speculations on the subject.

Since radio-activity was discovered at the end of the last century, it has been conceived that just as lead is known to be the end product of radium, so also may many of our other common and well-known elements be the end products of certain very heavy radio-active substances which existed in the far-off ages of the distant past and which, although they have apparently disappeared from our visible universe, may possibly have survived under conditions favorable for their preservation. It is also possible that these conditions may obtain in the interior regions of our sun and other stars. Having these clear possibilities in view let us return to the hypothetical element number 118, which is at least closely linked to a chain of six well-known gaseous elements by a clear-cut number series as previously shown. Let us name this element "hypon" for future reference, and let us give it, if you please, "a place in the sun."

We have already seen that hypon is radio-active and on account of the great size and complexity of its atoms it is reasonably certain to possess this property in a superlative degree. Its superactivity, however, must be greatly reduced by the tremendous gravitational pressure of its environment. It is highly probable, indeed, that the superactivity of hypon is so well regulated by this pressure that only sufficient energy is liberated to maintain the sun's radiation of heat and light constant and uniform through all the ages. There is evidence, however, of regular cyclic changes in solar radiation which must occur in obedience to certain natural laws and conditions with which we are not at present well acquainted.

If it is allowed that the radio-activity of hypon is influenced by pressure, it follows that as the pressure decreases the activity will increase and at a certain critical minimum point of pressure every atom in the mass of hypon will spontaneously disintegrate and then reform into other atoms of lighter weights and greater stability. These changes will be accompanied by a certain loss of original mass due to a partial dematerialization of the hypon atoms. Dematerialization in this sense means that during the disintegration of the ponderable hypon atoms a part of each atom is transformed into imponderable energy chiefly in the form of heat, this being a common feature in radio-active phenomena. When the disintegration is intermittent and occurs in various individual atoms scattered through the mass, as in a salt of radium, the production of heat energy is insignificant and may serve to raise the temperature of the mass only one or two degrees. In regard to the matter of hypon, however, the conditions and results are entirely different, for here we note the instant disintegration of countless myriads of heavy complex atoms involving a tremendous outburst of heat energy in the very midst of a crowd of light and simple atoms, thus providing all the requirements for a powerful explosive reaction. Briefly stated, hypon can not exist except under the stabilizing influence of great pressure, and if this pressure falls below a certain critical minimum the hypon will instantly explode with intense violence.

With this conception of hypon as our hypothesis we may evolve the following as a bit of cosmic history. "Once upon a time" there was a star which may have been as large as our sun or larger, but it was located so far away from our earth that nobody here had ever seen it.

This star contained a large amount of hypon, which was kept in a condition both safe and serviceable by gravitational pressure, so everything was well with the star and age after age rolled

on serenely until the arrival of a fatal hour when its long and tranquil existence was brought to a sudden and tragic end by a very strange catastrophe.

A series of transient waves of tremendous energy surging through space took a path so near to our star that the latter was terribly shaken so that its internal pressure dropped momentarily below the critical minimum of hypon. The result was instantaneous and too appalling for adequate description, for the mass of hypon detonated and the star, as such, ceased to exist. In its place there was a huge mass of intensely heated gas and vapor in furious chaotic commotion already distended to many times the size of the former star by the force of its explosion and still expanding at such a prodigious rate that in a comparatively short time it had spread out into space in all directions for millions and millions of miles. The eruption of matter and energy from the detonated hypon was vast beyond comprehension, but it had its limits, for its expansion could not go on indefinitely. In due time, therefore, the outward motion became slower and slower, then ceased, and the transcendently immense and brightly shining sphere floated stationary and unchanging in the ether for a considerable period. At length, however, the force of gravitation within and the piercing cold of space without combined to initiate the process of condensation, and the outermost shining clouds began to fall inward and mingle with the underlying mass. Contraction being thus well started, it must surely continue to a natural finish and we may now return to earth.

About a hundred years or more after the occurrence of this celestial cataclysm the first bright beam of its radiant light dawned on our planet, and we saw a pale white star in the sky where no star had ever been seen before. Then, to our wonder and amazement, this star began to brighten, and from week to week, and month to month, it grew still brighter and brighter until it was thought by many to be the brightest star in all the sky, and so it remained for a long time. Then gradually its light began to wane and week after week, and month after month, became weaker and weaker until it could hardly be seen and few people, excepting the astronomers, thought any more about it.

So it was that we watched the gradual development to its maximum brightness and beauty and then the slow decline of this wonderful and mysterious apparition in the sky which was called a nova, and which, if our hypothesis be the truth, was but the manifestation of atomic number 118, the seventh of our number series, hypon!

SCIENTIFIC EXPLORATION
A PHANTASY

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BEHIND a pair of plodding burros that bore his equipment and his meager personal belongings the scientific explorer tramped along through the heat of a tropical afternoon. Beneath his helmet the sweat coursed in furrows through the accumulation of dust on a face that showed strangely pale under the dirt and the bronze of the sun. The fever that had burned within him for days, and against which the few simple remedies that he had been able to carry with

him were of no avail, had sapped his strength, but he held doggedly on. The coast and a port were but a few days away.

The afternoon wore on and still the narrow trail through the crowding jungle revealed no evidence of a human habitation. The sun set and the fleeting tropical dusk was almost gone when a distant cock-crow gave evidence of the presence of a ranch. It was dark when the traveler came finally to the little group of thatch huts at the side of a stream and sent his native boy in to arrange for a bit of supper. Wearily the two stripped the packs from the animals and the boy threw before them such scanty fodder as he had been able to buy.

There came a call from one of the huts that their supper was ready, and the two went up. About a few gourd dishes on the dirt floor, illuminated only by a flaring torch, squatted the head of the household and his numerous brood, all dipping with their fingers into a common dish. The traveler received the courtesy of a crude stool upon which to sit and another that served for a table. Before him, in gourd dishes, were placed the coarse tortillas and the beans that constituted the customary and indeed almost the only food of the country.

It was poor food, the tortillas coarse and unappetizing, the beans tasting as if they were moldy, but the traveler had become inured to such things and above all he had learned to give no thought to the methods by which such food was prepared. With it disposed of there remained nothing to do but to go to bed, even if his illness and weariness had not of themselves demanded such action, for the slender literary resources of his pack were long since exhausted, as were the even more slender conversational possibilities of his native boy. With the people in the huts he could not converse, for their barbaric version of Spanish and his own slight knowledge of the classical form had but little in common.

He stretched his hammock between two trees and turned in. The multifarious sounds of the night—the barking of dogs, the squealing of pigs, the ghastly braying of the burros, the bellowing of bulls, the bawling of calves, the crying of babies, the sound of endless conversation from the huts—beat upon an ear rendered sensitive by illness. In spite of his weariness hours passed before he fell into a dream-troubled travesty of sleep.

About him the air hummed with mosquitoes.

Above the tropical forest sounded the distant drone of an aeroplane motor and the sinking sun flashed upon the plane's wings as it spiraled down to an extensive clearing among the trees upon the shore of a mighty river. The plane came to rest a short distance from a group of neat houses that filled one end of the clearing and as the occupants of the houses emerged the pilot climbed down and turned to assist a woman to alight.

From the approaching group of men and women, attired much after the fashion of the front porch loungers of a country club and one or two of whom carried tennis rackets, a man detached himself and stepped forward to greet the woman. "Welcome, Mrs. Catherton," said he, "to the base camp of the Ultimate Amazon Expedition. I am the director, Dr. Osmand. You will find it a bit rough here, but still I hope you will not consider your stay with us entirely unpleasant. Let me introduce some of my assistants." The group that had remained at a respectful distance came forward. "Mrs. Catherton, my first assistant, Mr. Hampstead—the chief of our radio service, Mr. Ashton—the chief of the bureau of public contact,

Mr. Smith—our chief artist, Miss Alderby—the chief of the photographic bureau, Mr. Wilson—our chief clerk, Miss Peters—the chief of transportation, Mr. Anderson."

He motioned to a white-clad native servant, who had already gathered up the newcomer's bags as they were unloaded from the plane. "Anastasio will show you to your room. We dine at seven."

About the tables of the mess hall, set with snowy napery and gleaming glass, there were grouped at least thirty of the more important members of the expeditionary staff, including those whom Mrs. Catherton had met and a number of other clerks, stenographers and underlings of various sorts. Dr. Osmand entered with Mrs. Catherton and motioned to them to be seated. "It had been my thought," he said, evidently continuing a conversation, "that we should follow the very admirable custom said to have been set by English gentlemen isolated in wild parts of the world and always dine in evening dress. One should never let himself go simply because he is separated from his fellows, and so I have always insisted that the members of my staff should never forget the respect due to themselves as well as to their colleagues. But it is so very hot here that I trust you will pardon us for dressing in white instead of the conventional black."

"It is a very great honor to have you with us, Mrs. Catherton," said the chief of the bureau of public contact, who was seated on her left. "I think every one here has read your books. For myself, I have especially enjoyed your 'Vengeance of the Tropics.' It is perfectly amazing that one who has never been in the tropics can so well describe them and so well understand their influence upon the soul of the white man. With the—er—ah—slight increase in knowledge of local color that you will doubtless obtain from your visit with us I feel sure that your next book will be even more wonderful. We are all looking forward to it and hoping that you will deal gently with us. Dr. Osmand has asked me to see that all available information and every possible resource are placed at your disposal. But we can discuss that later."

As the dinner concluded, the chief addressed the novelist. "We start our radio program at eight-thirty. I know this is short notice for you, but I feel sure you will rise to the occasion and say a few words about your first impressions of our expedition. When that is over we shall have a pre-view of one of the movies that we have been making."

Within the radio broadcasting room the announcer stood before the microphone. "This is the Ultimate Amazon Expedition, sent out by the Greatest Museum on Earth, broadcasting from our station in the heart of the Amazon forest. The famous novelist, Mrs. Catherton, known to all of you, is now visiting with us and she will speak to you."

The woman took her place before the microphone. "My dear friends and public. You who have read my books will be pleased to know that the sponsors of the Ultimate Amazon Expedition have generously permitted me to join this expedition in order that I may gain an even deeper understanding and appreciation of the tropics and that none of the possibilities of the expedition may be overlooked. There have been many scientific expeditions in the past that have literally thrown away the greatest products of their work. True they have brought back scientific specimens to be stored away and forgotten in museums and data to be entombed within scientific volumes that few will ever read. But they have entirely overlooked the human interest of their work. They have entirely ignored its literary possibilities. The world, which really sup-

ports these expeditions, has a right to receive in return something more than dry-as-dust geographical data or descriptions of new kinds of plants and animals. This the sponsors of this expedition thoroughly realize and so I have been asked to join their party in order that these literary possibilities may be fully utilized. It is with some trepidation that I decided to accept their invitation and to join in facing the discomforts and dangers of life in this great wilderness. But then one must be prepared to make some sacrifice . . ."

The weary traveler moaned and turned over restlessly in his hammock.

The broadcasting went on. The chief of the medical division was speaking. "The dangers of disease have been largely overcome. Our food is shipped to us directly, even including milk and butter, by fast planes that are equipped with refrigeration systems. These planes are a part of the efficient system of the Tropic Airways Company. Should you decide to spend your vacation in South America you will find no better medium of travel.

"When it has arrived here at our base camp the food is kept in perfect condition indefinitely by the wonderful refrigeration system installed for us by the Polar-air Company, and we send it out as needed to the outlying camps by hydroplane or by fast motor-boats that are able to traverse the smaller streams. These little boats are powered by Speedo motors, which are fed by Energo synthetic fuel and have never yet failed us in time of need. Our portable base camp buildings are built of Impervo fiber and are screened from the mosquitoes and other insects by that good copper screen made by the Nofly Screen Company . . ."

The traveler stirred again, brushing from his face the mosquitoes that had settled upon it.

Dr. Osmand sat in conference with the chief of his bureau of public relations. "See to it that she gets all the stuff she needs. In addition to her book she is going to write a number of short stories, so dig up some good incidents for her. You might get the Indians to put on a dance for her this evening. The museum has been raising the devil because our publicity stuff has lost its pep and the money for the continuation of the expedition isn't coming in as it should. Run some stronger references to our benefactors into the radio talks. They are paying well for their publicity and they claim they are entitled to lots of it. Maybe it is a bit crude, but you'll have to chance that. Give the Speedo people some sort of a story about how one of their gallant little engines brought a sick man down the river in time to save his life. Lay it on good and strong. Also see that a news story goes out about those three girl scouts that are coming down to join us. One more thing. Work up a good talk about the Henly Health Food stuff for to-morrow night. Better eat a little of the stuff yourself and see what it's actually like. That's all."

He pushed a button and a stenographer appeared, notebook in hand. "Letter to Stanley. Tell him I am definitely leaving for home the first of next month and have him arrange a series of speaking dates. Tell him to see to the publicity a little better than he did last time. We have sent the home office some new material that ought to go over big."

A clerk entered and spoke a name. "Send him in." A bespectacled individual in worn clothing entered. "See here, Miller, you fellows of the scientific staff aren't producing the stuff. How the devil is the publicity staff to work if you don't furnish them with material? You haven't turned in a thing for the last month that they can use at all."

The man flushed. "But, sir, we have been accumulating an enormous amount of scientific material . . ." "Bah! Your scientific material is well enough in its place, but how do you suppose this expedition is to be kept going on scientific material alone? It's publicity that counts in these days and if we don't get it we don't get the money to keep us going and if we don't keep going there won't be any chance to collect scientific material. We need some startling discoveries and if you can't make any, think some up. I don't give a damn for your scientific scruples. As a matter of fact, if it weren't that we need a scientific staff along to keep up appearances we wouldn't bother with you very long anyway. You haven't contributed anything to the movies that we are making. You can't write anything that's worth reading. You'll have to do something to earn your keep."

The man straightened up. "When I joined the staff of this expedition I was not aware that it would turn into a three-ring circus, an advertising scheme and a journalistic venture. My colleagues and I have already determined to leave to-morrow." The director burst out angrily, "There won't be any space in the planes for you. We never agreed to take you out any time you want to go."

The scientist smiled. "Men before us have traveled on foot and by canoe and every other way. The introduction of the white collar, the society element, the automobile, the private yacht and the aeroplane into scientific exploration is really a very recent thing. What men once did we can still do. My colleagues and I have already arranged for canoes. You may go to the devil."

Had any one been watching at the bedside of the sick man he might have been seen to smile as if some momentarily pleasing scene had passed on the troubled current of his dream.

A book-seller's stall glowed with the raw and barbaric colors of book jackets devoted to publisher's blurb, each endeavoring to outscream the others. Among them, side by side with detective thrillers, love stories of the mistresses of kings, popular novels, outlines of this and that, psychologies for salesmen, and outscreaming them all, two books.

"Tropic Night," by Catherton. "This gripping story of intrepid explorers in the gloomy depths of tropic forests . . . love interest running through it . . . a woman and a man, members of a scientific expedition into the miasmic forests of the Amazon . . . primitive passions bursting through the veneer . . . snakes . . . torture of swarming insects . . . gibbering of monkeys . . . sacrifice for science. . ."

"Heart of the Amazon," by Osmand. "This epic tale of daring scientific explorers, enduring the dangers of the tropic jungles, suffering the risk of death from fever and wild animals, plunging fearlessly into the unknown to wrest from it the age-old secrets of the mysterious life that haunts the tropic trails . . . aided by the devices of modern science . . . tremendous contribution . . . its author takes his place as one of the most eminent of scientific men . . ."

The man in the hammock awoke from his troubled sleep with the first light of dawn. Another breakfast of the inescapable tortillas and the inevitable frijoles and then once more behind the plodding burros that carried his equipment and his meager personal belongings he set his feet on the trail to the coast.

THAT SCIENTIFIC HOLIDAY

By Professor A. W. MEYER

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He who proposes a holiday does not take a very large chance on popular acclaim. A day off always is an inviting prospect. The carefree, the irresponsible, the weary, all can forego, or try to at least, not only all thought of the future, but all thought of the present. A joyful or delirious present always helps to efface unpleasant memories, and many of us still like to have a day when and a place where we may say: "Hier bin ich Mensch. Hier darf ich's sein."

Unless they who suggest a scientific holiday consult those without whose sanction and cooperation it can not be had, the suggestion will remain an idle one. For, contrary to the ways of the crowd, scientists are wont to hang "Don't disturb" signs on the doors of their sanctuaries on holidays and lock themselves in, so that they may yield themselves more completely to the lure of the unknown, or, as some people would have it, to the forces of darkness. So a holiday for science without the cooperation of men of science could only be a Volsteadian holiday and would bring us bootleg science as well as bootleg whiskey. Surely, not even the eminent divine, who, among others, suggested such a holiday to men of science, could be thrilled by such a prospect; and it is well to remember that it is not long since the world knew bootleg science, or at least so regarded much of it.

Although it may be true that we learn nothing from history, in spite of the fact that she can teach us so much and so well, I venture to think that it would be possible to revive the old story of bootleg science in a telling way. Galilei and Servetus might tell their story so that people would listen and, listening, would heed the lesson. The rigors of the dungeon and the smell of human flesh, even when burned slowly at the stake on a bright Sunday morning, may not have lingered long in human memory, but in these modern days it might be possible to reawaken that memory with telling effect, for science touches our daily lives in so many ways. Even the untutored could realize what interfering with its growth and living without its commonest fruits might mean.

An untidy or uncomfortable man seldom is happy, and a sufferer still more rarely so. Even common folk know that soap, hot water, towels, clothes and shelter are indispensable and have much to do with their happiness. Add to this clean and sanitary food, comfortable sleep, a wealth of printed matter and access to music and art, ready transportation and communication, skilful help and care and surcease from pain in times of physical distress, and you have some of the commoner blessings of science which have added immeasurably to the happiness of civilized men. Without any of the fruits of science our happiness could be only as that of brute creation, which may seem happy merely because it is dumb, and also without imagination or compassion or remorse.

They who suggest a holiday for science probably forget that it once had a long holiday during dark ages in which life was harsh and hard, and when the human race bore the grievous burdens of plague and pestilence, as well as the dire handicaps of filth, starvation and lack of shelter. In those "good old days" primitive man shared not only the lot of wild creatures, but in a measure and in some respects also the more forbidding

lot of those of the stall. The millennia in which man was indifferent to his surroundings constitute a scientific holiday in fact. Those were the days when man felt no inspiration, dreamt no dreams and saw no visions. Later, when he was stirred into action and became curious about his surroundings, the birth of science had come. Although the entire period of modern science is but as a moment in the long span of man's existence on earth, if those who desire a scientific holiday would have to live a life unrelieved by the fruits of science and by the joy of an inquiring mind, a scientific holiday would lose all its charm.

But this really is not what the sponsors for a scientific holiday want. They merely want to dispense with the future fruits of science. They mean to keep all that which the tree of science has borne in the past, but bid it cease blossoming for a time. They do not want the humanitarian service of science to stop. They do not wish the hand of the nurse and the doctor to be stayed in their ministrations to the sick and the maimed or have the activities of the sanitarian in behalf of public health discontinued. They merely wish to live on the past. This may sound reasonable enough, but is it really so?

Suppose, for example, that the present moment were that of the discovery of anesthesia. Then, what these people really suggest is that the severest suffering should continue unrelieved, that legs should be sawed off and abdomens opened without the relief that unconsciousness only can bring. They would have the sufferer who needs relief by an operation again be held down by force like the worm or the fish on the hook or the cockerel on the barrel. These people would ask that typhoid, diphtheria, smallpox and the plague shall be permitted to go their way as unhindered as they once did and that every house of tender mercy again become a house of needless pain. The suggestion for a scientific holiday can fail to mean this only if it can be assumed that all great discoveries have already been made and that science has nothing more to offer humanity. But were this so, then the suggestion of a scientific holiday is meaningless.

Insulin and vitamins have just been added to the triumphs of medical science, and who can tell what great discovery is in the offing at this very moment. What the advocates of a holiday for scientists apparently fail to realize is that all humanitarian and sanitary measures rest upon pure science, and that it is hence against it that their fears are, in fact, directed. It is exactly these sciences that are the foundations of progress. Here, for example, lies a man severely burned and swollen beyond recognition. Even the nurses and doctors avert their eyes at the harrowing spectacle, and years later dislike to recall it. We shall pass by the long, agonizing and sleepless nights and days which the victim would have to bear if there were no hospitals and if there were no drugs to deaden feeling and prevent infection. But suppose every doctor's office contained the means of neutralizing the effect of the poisons produced in the burning of the flesh and hence could forestall the dreaded early collapse and later complications and perhaps death. Were this possible, wife and children, perhaps far distant from the scene of tragedy, could be saved the dreadful suspense of many uncertain days, and could often be apprised almost at once that all would be well in the end. Is there any man so stupid or so cruel as to want to stay the hand of him who might bring us this relief? Could those who suggest a holiday for science go through the nerve-wracking experience of witnessing such pitiable spectacles as those which often follow severe burns or

scalds or be so unfortunate as to furnish such a spectacle themselves, they would be the first to further the progress of science instead of wanting to halt it even for a moment, for surely some moment will tell the secret of cancer and of leprosy.

It is only the investigator in pure science who can determine what the toxines are that produce the dreaded effects of burns, who can learn how they act and how they may be neutralized; and until these things are known, doctors and nurses, be they ever so faithful and competent, will remain helpless to relieve the greatest sufferer. Surely no man of God will want to be responsible for delay in this matter. A brief holiday could be of no avail to any one, and a long one would break all continuity with the past. It is possible to bid the tree of science cease growing, but no man can cause it to blossom again forthwith. Dead trees can not be revived; and, like all other trees, the tree of science does not prosper without care. Be he ever so humble, the man of science can not be made to arise by a wave of the magician's wand. He too is born, and dependent on the past. Not even a genius could do much if compelled to start anew.

He who created all things must also have created the scientist, and a scientific holiday implies that scientists must, of necessity, become misfits or idlers. Scientists did not create their own predilections. These were born with them quite as much as the predilections of any other group, and they can not successfully cultivate a taste for things for which they are not fitted. The curiosity which they evince concerning their surroundings is inborn, not acquired.

Men do not create, but develop, their capacities, and if science is not a part of the eternal scheme of things, then it must lie within the power of the groping, puny mind of man to circumvent the Maker of all things. Surely not even the most confident or arrogant man of science would claim this. And if no one can, or tries to, outwit nature or the Creator, then why all this alarm, for the man of science, too, is a worker in the vineyard of the Lord, misunderstand and misuse him in war or peace though we may.

The idea that science shall mark time so that somebody else may catch up is, indeed, a novel one. It implies that others can not or will not quicken their pace. Science must move on. It is not a mere sapper, but lays foundations without which progress is impossible in modern life. All uncivilized peoples have had abundant time to achieve greater happiness than the civilized, had this been possible without science, and if there be those who perchance hold that aborigines have indeed done so, let them volunteer to share their bestial life.

It also is well to remember that the so-called onward march of civilization never has presented a straight front. It always has had its scouts and its stragglers, as well as its main line, and it probably always will have them, with a long stretch from front to rear. Both ends may be happy, but only because the rear is unaware of, or else because it enjoys the protection of the advance guard.

Until progress in science ceases altogether, readjustments in our views regarding the world of nature are inevitable. If we do not make these inevitable readjustments ourselves, we will merely be passing the burden on to others and our children will of necessity have to make them instead. However justifiable it may be to visit pecuniary burdens upon future generations, we surely should not visit intellectual burdens upon them in addition.

The suggestion for a scientific holiday seems but a jest, and, when made in earnest, can not be the fruit of either the humanities or of religion, but must

arise from the fears of men who have lost their way, as others did before them. A life in conformity with the laws of science need give no one trouble, for it implies living in conformity with the laws of nature, which also must be the laws of God. If there be a conflict between the laws of matter and those of the spirit, it must have been so ordained, and it can not be in the power of any man to avoid that conflict. If, on the other hand, no such conflict exists, then he who obeys the laws of nature need not violate those of the spirit. To live in conformity with natural laws may not of itself bring happiness, but it surely will avoid much unhappiness.

Science can not solve the riddle of the universe, but neither has anything else done so. All roads have been blind alleys and an *ipse dixit* remains just that, no matter whether it comes from the lips of the man of science or from those of the man of God, and can bring happiness only to those who are pleased to accept it with unquestioning faith.

In the wide span of human history it was but as yesterday that the use of knives and forks and spoons was declared to be sacrilegious because the Creator had provided ten fingers for these very purposes. There are those living now who remember that the use of anesthesia in childbirth was denounced because it was thought to remove the curse upon Eve from woman, and thus circumvent the intentions of the Creator.

They who would halt the builders in the temple of science to allay groundless fears and to avoid inevitable readjustments in conceptions regarding the universe are men of little faith. Take heart, I say, and let not the arrogant, the overconfident and overzealous among men of science frighten you with boastful things. False prophets in the field of science, as in the realm of religion, are sure to be revealed in their true light, and it is our fears that often bring us our worst perplexities. If, as men blinded by prejudice or wrath, we wreak our vengeance upon things that have freed us from grievous bonds, we may again become galley slaves brutally scourged to foul dungeons or pitilessly consigned to the boundless deep.

ON THE DIFFICULTY OF CONVEYING IDEAS

By Dr. BEVERLY L. CLARKE

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EXCHANGE of thought through the medium of words is hedged about by difficulties which stamp informal conversation definitely as an art and not a science. In other words, the *idea* in the mind of the speaker is transmitted, through language, not pure and untainted and "under seal," as we should wish, but tinged and twisted and disfigured. This is partly owing to the inherent imperfections of language and of our conventional method of translating thought into words, and partly to personal idiosyncrasies of the minds of both speaker and listener. These latter operate to cause the speaker to say something different from what he is thinking, and the listener to construct in his mind an idea different even from that implied in those inaccurate words.

There is a remarkably pertinent analogy in the radio. A band plays in New York, and the sound waves enter the microphone and are translated into

electricity. The method of translation is not perfect, and the electrical waves are not exact replicas of the sound waves. The electrical impulses are further changed and sent out into space as "ether" waves. Between the broadcasting station in New York and the receiver in Chicago the "ether" wave is subjected to countless forces which further distort it and render it less a "literal translation" from sound into electricity. In the receiver the poor wave is further mauled by mechanical and electrical imperfections, is retranslated into sound and finally arrives bearing but little real resemblance to the band music in New York, and accompanied by a host of squeaks and squeals and buzzes and wails that it picked up on its way or in the receiver itself.

So it is with the broadcasting of thought. The transmitter and the receiver are both imperfect, and insist on making contributions and paraphrasings of their own. The medium—language—abounds with static and cross-currents, and "fading" is not altogether unknown.

Perhaps the chief difficulty lies in our method of attempting to frame ideas into words. Language is inherently inadequate for the full expression of the simplest idea. Language is man-made, and ideas are sublime; they are possibly the very atoms of consciousness, of life; they are essentially transcendental and intangible.

If we attempt to elaborate on the concept "idea," to delve deeply into its form and essence, and so to characterize it by a statement of its peculiar qualities and attributes that its utterance by a speaker will convey exactly the same impression to every listening mind, then we become immediately conscious of the limitations of language. "Idea," as used in the present essay, is to be loosely identified with the more current word "thought," in the sense of the "quantum" of thinking; and the thought is the thing-in-itself, the reality, the actual noumenon which results from the activity of mind. The thought, or the idea, is thus suggested as a mere synonym for mind-in-action; static, inactive mind, is unknown to us and inconceivable by us, and is the utterly unattainable thing-in-itself of which the idea is the phenomenon or manifestation in the next lower sphere. Similarly, the attempted expression of a thought in language is an imperfect manifestation, in a still lower sphere, of the idea.

Thus verbal expression is twice removed from the absolute truth, and is grossly distorted in each of the two steps. It is as if we were translating a German passage, first into French, which corresponds to passing from absolute truth or static mind to the result of mind-in-action or the idea, and then from the French version into English, which parallels our attempts to formulate ideas into words. The translations lose something at each step, and the final English version may easily be unrecognizable to the German author. Is it not possible that a correspondingly important loss is suffered in passing by this tortuous route from the absolute truth to expression in language?

In any consideration of the transmission of ideas from person to person through language, it is manifestly necessary to make the empirical assumption that the word "idea" means the same thing to every mind. Any conclusions we may reach will have meaning and significance only in so far as this assumption is warranted. Fortunately, and rather paradoxically, the concept "idea" seems, in spite of its extreme abstractness, to possess in extraordinary degree this quality of universality of significance.

If we grant to "idea" this universality of significance, then we avoid the first stumbling-block which the difficulty of conveying ideas redundantly places in the way of any consideration of this diffi-

culty as an abstraction. Even though we might not be entirely justified in this simplifying assumption, we should have to make it anyway; otherwise there would be no place to begin.

Because of some peculiarity in the way our minds are made, we are compelled to make our thoughts articulate either by stating an abstract generalization or by quoting a specific example. Without endless circumlocution there is no middle ground. Neither one of these is entirely satisfactory and neither one is exactly what we want to say. If, in extemporaneous conversation, we express our thought of the moment by some broad, sweeping, all-inclusive generalization, such as, "My life is a pretty gloomy affair," then we say a great deal more than we intend to say. Still, if we trace the origin of that thought and put that little stimulus into words, it may turn out to be, "I have a pain in my stomach from that lobster, which makes me very uncomfortable." To say so baldly would, however, fall far short of the mark of accurately rendering what is in our mind; because the stomach ache which possesses our attention for the moment has acted as a nucleus around which has gathered a number of other equally minor matters of similar character drawn from memory, the result being a sizable heterogeneous mass which, for the moment, appears homogeneous and important.

In this day, when brevity and succinctness of expression are at a premium and catch-phrases and slogans are applauded as linguistic achievements, any tendency towards circumlocution is frowned upon, and the writer or speaker who attempts, by qualifying phrases and logical embellishments, to make his words render his thoughts more truly is damned as a pedantic bore, bombastic and heavy.

So it appears that there is indeed no possible middle ground. Also, it appears to each of us, on introspection, that the mind, in its operation of fabricating ideas, makes use of a form which is neither abstract nor narrowly specific, but which lies somewhere between the two. The mind thinks, then, in a framework which, through some curious caprice of the nature of things, has no exact counterpart in linguistic expression.

Let us turn now to the hearer of the words which are spoken in an attempt to convey to his mind the ideas which originated in another mind. This person receives an impression in his brain through the spoken words which we shall, for the moment, assume to be identical with the best possible translation into words that the speaker could make of his idea. The recipient then retranslates this impression into thought substance. The assumption is usually made that, after these several translations and retranslations, the idea which finally lodges in the hearer's mind is a faithful reproduction of that which was present in the speaker's mind. But this is obviously not true; for one thing, because of the indefiniteness and inefficiency which characterizes this shift from a form which is definitely abstract or definitely specific, to one which must partake in some intangible way of both in order to fit into the matrix of the mind.

And there are other factors operative which tend greatly to increase the degree of inaccuracy possible. One of these is that, in passing from the abstract (or from the specific) to this peculiar intermediate point, it is necessary for the mind to use its powers of reason and analysis and to exercise its faculty of judgment: it must apply criteria, weigh evidence and act as an analyzer of motives. For its task is to try to fathom out the real idea in the other person's mind; the words are only a clue, and with their reception the detective work only begins. And it will be generally admitted that, unless we attend closely to make it otherwise, the mind is inclined to be very decidedly biased and preju-

diced in its judgments and analyses. The bias is derived from the past experience and is moulded by the present mood of the mind itself. The mind which attempts to translate words heard into an idea must perforce do it in the same way as it would have performed the reverse act of changing its own idea into words. The indications are that no one mind is exactly like another in the method it uses for this purpose, because, as stated, its own peculiar method is determined by its past history and present state. Thus, on hearing the statement, "My life is a pretty gloomy affair," the listener, if by chance he had a digestive system which rose above mollusks and bivalves, would not in a thousand years deduce from the evidence at hand that this devastating affirmation had such an origin. He might, on the other hand, have learned of a fall in certain railroad stocks in which he knew his interlocutor to be interested, and the probabilities are that he would attribute his pessimistic statement to this—and be altogether wrong.

Words are to ideas what weight is to matter: their effect is to impede the movement, distort the form and thoroughly to cloak the essential lightness and ethereality that properly belong to ideas. But their offense is ranker even than this. We have been discussing the shortcomings of the verbal expression, that is, of the group of words, in expressing an idea. But it is manifest that the individual words constitute the root of the trouble. Consider what a simple substantive, such as "dog," means to various minds. To me, when I forcibly close my mind to the several specific dogs with which I have been familiar, and try to visualize the general abstraction "dog," there arises a picture of a hybrid beast with long, flabby, white ears, the kind, trusting physiognomy of a collie, an emaciated body, creamy-white mottled with black spots, a most incongruous abbreviated tail, and dark-colored spindly legs. Evidently this bizarre creation is a composite of a number of dogs whose external characters have stuck in my memory. Try as hard as I will, I can not devise a picture of "dog" which satisfies my desire for the universal abstraction divorced from individuals. You, the reader, will doubtless find in your mind a picture of "dog" considerably different from mine, for the simple reason that you and I have moved in different dog societies. All of which admirably illustrates the point that any word will mean something different to every one who hears it. With some words the discrepancy is great, with others small; but discrepancy there always is. If such common and universally familiar words like "dog," "man," "boat," etc., suffer from lack of stability to such an extent, how can we have faith at all in abstract words like "love," "good" and "right"? Plato wrote his "Republic," a lengthy work, in an attempt to establish a definite meaning for one little word—"justice."

Thus we must conclude that when a person pronounces a single word in an attempt to convey an idea to another, he has little assurance that the image aroused in the other's mind will bear much resemblance to that in his own. The mental image which a word brings up is moulded and fashioned by the past experience of the individual. Each time a dog is seen a contribution is made to the individual's concept "dog"; and each time a dog is thought of in relation to other ideas, emotions or events the concept is further amplified or altered or, it may be, drastically redesigned. Thus a man who was bitten by a mad dog would inevitably allow this particular dog a large share in the development of the abstract concept.

If there exists this much uncertainty about single words, the frightful risks we take when we string several words together may readily be imagined. For here we introduce the added danger of

the attempted fusion of several abstract concepts to make a single concept less abstract and more particular. For this reason, the total ambiguity of the verbal expression is more than the sum of the ambiguities of its component words, by an amount which defies estimation because it deals with the transcendental matter of *relation*. It is truly marvelous that, with this formidable misfit of language with ideas, one human being is able to hold any sort of mutually intelligible intercourse with another. What is lacking in this field is similar to what Einstein found to be lacking in the physical universe: a universal frame of reference, rigid and unchanging from point to point in the universe—or from individual mind to individual mind in the sphere under discussion.

Besides the use of words simply as practical symbols for ideas, there are of course other methods of conveying from one mind to another the results of mind-in-action. If we designate the method which we have been discussing as the literal method, we may group all others under the esthetic or symbolic method. In the literal method words are simply convenient and practical shorthand characters for definite ideas. The important distinction is that in the literal method, for every possible idea there is a word or a word-group which stands for this idea and for no other. This would be possible theoretically if it were true that words can unambiguously express an idea, because one can conceive of an infinite variety of words or word combinations to fit the infinite number of ideas; but it does not work in practice because, as we have seen, words and ideas are essentially incommensurable. The literal use of words in straight prose and the use of pictures as aids in language instruction, such as the picture of some animal with its written name attached, are examples.

At the opposite pole lies the esthetic method. Here the analysis of purpose and motive is difficult. The physical form of the medium used for the conveyance of the idea is not to be regarded as a literal and invariable symbol for the single idea, but rather for an intricate complex of ideas which resists analysis. Thus, while one can conceive of assigning a fairly definite and nearly universal meaning to "dog," no two people, and least of all no two estheticians, can agree upon the fundamental idea which a portrait of Titian or a symphony of Beethoven ought to convey.

But the esthetic and the literal methods are, in one sense, two methods of doing the same thing. An artist, or a composer, or a poet, in fashioning a symbol in his particular medium, has one thing in common with the prosaic utterer of a brief, unembellished verbal expression: he is attempting to translate into another medium an idea or an idea-complex, which is in his mind. The two operations are fully analogous: both have as their unconscious purposes the desire to express an idea; both make use of a medium. The difference is that with words the ideal universality of significance is comparatively closely realized; whereas in the arts the same symbol (poem, painting, sculpture, etc.) admittedly produces widely differing reactions in different individuals. No one but an idiot would picture a horse in his mind when some one pronounced "cat"; but there could be selected a group of people, none of whom would be idiots, whose individual opinions of some picture or symphony would run the adjectival gamut from "hideous" to "celestial."

That this is only a difference of degree when the verbal and artistic forms of expression are concerned is illustrated by the facility with which people justify diametrically opposed lines of conduct by the same written words; witness the familiar platitude, which is true enough, that "you can prove anything by the Bible." Prose such as found in legal documents falls under literal method,

while poetry makes use of the esthetic method; but most poetry contains considerable prose and most prose considerable poetry. There are extremes, as, on the one hand, verbal statements of mathematical laws, where a serious attempt is made completely to eliminate ambiguity, and, on the other, certain sacred writings of the Orientals, with whom obscurity seems a virtue and an index of profundity. But there are all possible gradations between the extremes, and the two methods of conveying ideas nearly always overlap.

But it is perfectly evident that the artistic symbol is ill adapted to the definite, unambiguous conveyance of an idea. The user of the esthetic method does not imagine that his exact mental content will pass over, through the medium of his art, to another mind; he knows well enough that it will not. The idea-complex which the sight or the hearing of his artistic product will induce in another mind depends almost entirely upon the past history of that mind, upon its peculiarities, its ancestral heritages, its momentary caprices, in a word upon the *personality* of the owner of the mind.

How then can a sane man devote himself to the expression of his ideas by a method which gives no promise of accurately conveying them to other minds? Are we to conclude that the employment of an artistic medium of expression is a vain and futile occupation? We are indeed so bound, if we make no distinction between the motives which prompt the user of the literal method and those which are at the root of artistic endeavor. But we are intuitively averse to placing Michael Angelo, who was a Symbolist, at a lower level in the scale of mind than the Italian fruit peddler, who is a Literalist. So we cast about for some illuminating difference in motive.

This difference in motive is soon apparent. The artistic urge comes from a subconscious conviction that the difficulties of conveying ideas are insurmountable. It is a recognition by the artist that his idea-complex *can not* be adequately and completely transmitted to another mind. Released, by this conviction of the futility of the literal method, from the cramping chains of prose verbal expression, he turns joyfully to the more fluid media of art, and there moulds, paints or composes a symbol which he strives to make a perfect physical correlate of his idea. By the same action his obligations to the other minds that fill the world are dissolved, and he balances himself upon the cold pinnacle of isolated individualism; for when he becomes an artist his purpose ceases to be the *conveyance* of ideas, and comes to be simply their *expression;* his artistic urge is satisfied completely by having carved out of the formless medium a perfect, literal symbol of his ideas; he has not the slightest concern with what ideas his product arouses in other minds.

If we granted the validity of this interpretation of the impulse to artistic creation, we are in a position to make some generalizations about the character of the true artist, the flattering nature of which would have a tendency to induce in our artist an excessive vanity—were he not a *true* artist and hence immune to flattery and utterly indifferent to what we may say or write about him. If our explanation of his motive is correct, the artist must be placed, by all real standards, above those of us who are not irresistibly impelled to create; for this impulse is the direct result of the existence in the mind or soul of idea-complexes too abstract, involved and advanced to admit of their satisfactory expression by the literal method: if the content of the mind is of the simpler variety, the literal method will suffice; and the spontaneous confinement of an individual to this mode of expression is an index to a mental or psychical caliber

inferior to that of his neighbor the artist who deals in symbols and scorns praise.

But before the professional dealer in artistic symbols may gracefully accept this pean of praise, he has the difficult task of justifying his claim to the title of true artist. It is not sufficient that he feel the urge to paint or write romances or play the piano; it is not merely that he allow these impulses full play and acquire the ability to produce from his medium creations which draw praise from the critics and acclaim from the populace. For the true artist success is measured not by the pleasing impression produced on others but by the accuracy and completeness with which the idea-complex in his mind finds expression in the medium; it is a matter concerning the artist and his medium exclusively, and incidental auditors, witnesses or readers are simply interlopers who indelicately intrude upon a private affair and are to be ignored.

Now it is a matter of common knowledge that artists, as a class, are deplorably vain about their creations. What prima donna regards the audience as indelicate intruders? Or what pianist laboriously masters the intricacies of Bach or Beethoven for the sole purpose of performing them for his own ears? Are we then to refuse to any whom we call artists the supreme title of *true* artist? Happily we are not forced, by logic, to such an extremity. It is only necessary to remember that an individual is not homogeneous but extremely heterogeneous, and that the human personality is not simple and static but many-sided and changeful. We avoid the difficulty by considering that the personality of an individual is compounded, like a chemical substance, of different proportions of a number of elements, one of which may or may not be that of pure artistry. When this element reaches a certain degree of predominance, the individual takes on the characteristics we commonly associate with the artistic type. From then on, with increasing proportion of the artistic component, the artist approaches nearer and nearer to the true artist.

Plainly, we are postulating true artistry as an ideal state, probably unattainable in practice. Like the truly just or the truly good man, the true artist is of the nature of a mathematical limit, to which we can approach as closely as we please—theoretically—but which we can never quite reach, even theoretically.

It seems, then, that the difficulty of conveying ideas is not, after all, so much to be deplored. For it is this very difficulty that has given birth to art; and few will deny that we are indebted to these rare and brilliant flames of pure artistry which now and again illumine the world, for most that is excellent in this life.

SOUND PERCEPTION BY INSECTS

By Dr. B. B. FULTON

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IT would seem like a very foolish whim of nature to provide many insects with elaborate sound-producing mechanisms if they could not hear their own music. But any one who studies living insects must notice their apparent indifference to the sounds we make. You can shout at an insect until you are blue in the face, and as long as no air currents strike it the insect goes about its business as if nothing had happened. Either it does not hear you or if it does it seems to consider the source and pays not the slightest attention. This lack of response to sounds has led many people to believe that insects are unable to hear.

The most commonly accepted theory regarding the utility of insect sounds is that they are mating calls. If insects do not hear, this theory would have to be discarded. Fabre claims to have fired two mortars near singing cicadas without affecting their song. He says, "If any one should tell me that cicadas strum on their noisy instruments without giving thought to the sound produced and for the sheer pleasure of feeling themselves alive, just as we rub our hands in a moment of satisfaction, I would not be greatly shocked." Lutz questions whether the sounds produced by some insects have any more purpose than the snoring of a man asleep or the rattling of a Ford. Forel, after experimenting with various types of sounds with a number of different insects, concludes that only crickets and certain other Orthoptera actually hear, but that all insects are remarkably sensitive through their tactile sense to vibrations of the ground or objects on which they are standing.

If it could be proved that insects do not hear, then we would have to find a new use for certain peculiar structures which insect anatomists call auditory organs. Our knowledge of these organs is the result of many years of painstaking research, mainly by German entomologists. The first hearing organs to be investigated were those associated with an external tympanum or ear-drum which any one can find with a hand lens on the front legs of crickets and katydids and at the base of the abdomen of short-horned grasshoppers. The sensory cells associated with all such organs were found to be characterized by the presence of a peculiar hollow rod which may be called the auditory peg. This tubular structure is imbedded in one end of a spindle-shaped sensory cell and the axis fiber of the cell extends through the tube just as a fiddle-string might be stretched through the center of a length of pipe. In the other direction the axis fiber is connected by nerves with the central nervous system of the insect. It would require about seven hundred auditory pegs placed end to end to measure an inch.

Further investigation revealed the fact that insects of various groups possess sensory cells with auditory pegs which are not associated with ear-drums. They are usually found in bundles and suspended by means of ligaments between two immovable points of the insect's body wall in such places as to be free from the movements of the inner organs. They are found in larvae as well as adult forms, and in various body regions, such as segments of the abdomen, in joints of the antennae, in legs and in wing veins. It is believed that

the integument of insects, like the eardrums of vertebrates, may act as a sounding board to pick up sound waves from the air and transmit them to the auditory sensory cells.

Large bundles of auditory pegs have been found in the enlarged basal segment of the antennae of mosquitoes and many other insects. It is believed that the small bristles on the outer segments of the antennae pick up the vibrations and transfer them to the nerve endings in the basal segment. In the case of the male mosquito whose bristles decrease in length toward the tip of the antenna, it has been demonstrated that different musical notes will cause different sets of bristles to vibrate. This experiment does not actually prove that mosquitoes hear with their antennae any more than it could be proved that a piano hears when its wires are set into sympathetic vibration by sound waves. The mosquito gave no indication that it perceived any sensation of sound.

The difficulty in demonstrating that an insect hears has been to find one that will react frequently to some sound that we can make. If all animals reacted to every sound perceived, what a lively place the world would be. But a few cases have been discovered where for some unknown reason an insect will show a definite movement in response to a sound.

Turner experimented with some of the large native silkworm moths and found that by suddenly sounding an organ pipe or whistle in the insectary the moths would lift their wings as if about to fly. This happened in a sufficient number of cases to show that the movement was definitely associated with the sound. Precautions were taken to prevent vibrations reaching the moths in any other way than as sound waves in the air. The moths responded to a rather wide range of sound waves.

One species, *Telea polyphemus*, responded very little to the sound, for out of seventy-eight trials the moths gave only three positive responses. The question was whether this species was hard of hearing or merely unemotional. To test this he performed some experiments on one individual at a time. After sounding the organ pipe five times he would take this moth and squeeze it, throw it down on its back and manhandle it in various ways without seriously hurting it. This was repeated a number of times and in this way he claims to have educated several specimens so that they moved their wings vigorously whenever the pipe sounded and did so on the following day also.

Turner and Schwartz tested the auditory powers of certain moths of the genus *Catocala* which have a habit of resting on tree trunks during the day, their brightly colored hind wings covered by dull-colored fore-wings that blend with the bark. Whenever they found one of the moths in the woods one of the partners in this experiment would sneak up on the opposite side of the tree and blow a high-pitched Galton whistle, while the other would observe the moth at a safe distance. In the majority of trials the moth either flew or fluttered its wings at the first sound of the whistle.

Minnich found that the larvae of the mourning-cloak butterfly, *Vanessa antiopa*, would respond to a sound stimulus by suddenly raising the anterior third of the body. When the body hairs were singed off or loaded with water or flour the response was reduced or abolished. During molting periods, when the old and new hairs became partly disconnected, hearing seemed to be impaired. It was evident that the hairs were organs of sound perception. The larvae responded to a wide range of sounds from 32 to 1,024 vibrations per second.

More recently Abott has demonstrated a more limited degree of sound perception in the yellow-necked caterpillars, *Datana perspicua*. These larvae feed in

colonies on sumac and when disturbed elevate the front and rear portions of their bodies. They responded in this manner when a pipe was sounded if the note was either middle C or F sharp above middle C. Here again the body hairs seemed to be associated with sound perception, for the response was destroyed when the hairs were sprayed with water or diluted shellac. In neither this experiment nor the last was it shown that the hairs are associated with auditory sensory cells.

During all the years that entomologists have debated the question of whether insects can hear, and while they planned and carried out careful experiments to prove it, a modest, retiring insect has been steadily broadcasting to the world that it can hear its own kind. That insect, the snowy tree cricket, is seldom seen, but its song has been heard and admired the country over. No experiment is necessary to show that it can hear; one has only to listen and observe. The measured, mellow notes, as they issue from the thicket on a summer night, seem to be the effort of a single singer, but in reality they may be the perfectly synchronized music of a dozen or more. This insect is a lover of rhythm and each individual is part of a leaderless orchestra. In what other way can these musicians of the dark coordinate their notes except by the sense of hearing?

I have also observed this habit of synchronized stridulation in two species of the katydid family, but it is not common among singing insects. Probably others fail to practice it because they lack a talent for rhythm and not because they are unable to hear each other.

In northern Arizona I have observed a species of grasshopper, *Circotettix coconino* Rhen, which effects periodical community outbursts of a loud rattling noise made with the wings while putting on an exhibition of stunt flying. At intervals of about half an hour I would hear some of these grasshoppers flying in the distance. The sound would approach and suddenly several of the insects near by would take to the air and make the desert ring with a terrible clatter. Then they would settle down and I would hear the wave of disturbance passing on to other parts. How do these grasshoppers, resting on the ground, often under the plants, know when it is time to perform their aerial antics except by the sense of hearing?

It has been demonstrated by experiment and observation that some insects can detect sounds. We have the word of the anatomists that a great many and perhaps all insects possess sensory organs containing auditory pegs, which seem to be better fitted for hearing than for any other function. It seemed to me desirable to tie up the two lines of evidence by an actual demonstration that the organs in question are the ones concerned with hearing.

The crickets and katydids that practice synchronized stridulation are ideal subjects for such an experiment. They demonstrate hearing of their own accord and they wear their auditory pegs in specialized structures on their front legs where they can easily be removed without seriously injuring the owner. What could be simpler?

The first species I experimented with was a short-winged katydid, *Amblycorypha rotundifolia brachyptera* Ball, an inhabitant of the Iowa prairies. The song of this insect is a series of twenty to thirty sharp metallic rasps at the rate of about four per second. Each series of notes is followed by a rest period of about five seconds. In common with all crickets and katydids the sound is made by short wing movements. A specialized file-like vein on the under side of one fore-wing near the base is scraped by the edge of the opposite wing. The synchronism exhibited by ten males that I placed in a cage was almost perfect. The song of the group was continuous, and as each singer started its series of

notes anew it would fall in with the general cadence. It was only by detecting slight variations in the quality and volume of the chorus that one could be aware of the pauses in the individual songs.

I next placed four of the singers in another cage at some distance from the first and with a small scissors cut off their front tibiae, leaving them without their supposed hearing organs. On the third night after the operation two of the mutilated katydids sang more or less continuously. The notes were not synchronized except as they happened to sound together at times. The two males sang at slightly different individual rates so that if they started a series of notes in unison, they would be sounding alternately at the close. Later, three or four of the deaf katydids could be heard singing at once, with a confusion of sounds that would have inspired a composer of rhapsodies.

The normal katydids continued playing their synchronized music. In order to be doubly sure that my expectations did not deceive my senses, I requested some one who had no knowledge of the experiment to listen for a few minutes at each cage. This observer noted at once that the song was rhythmical in one cage and a medley of confused sounds in the other.

The next number on the experimental program was a male chorus of snowy tree crickets, *Oecanthus niveus* De Geer. Their song is a clear, whistling note rhythmically repeated for an indefinite period. One lot of the crickets had their ears amputated as in the previous experiment, and the results were essentially the same. When only two of the mutilated musicians were singing at once the notes were apparently synchronized at regular intervals, separated by periods during which the notes sounded alternately. This effect is produced by any two sets of rhythmically repeated sounds having slightly different frequencies. Each cricket sang at its own individual rate uninfluenced by the song of others in the same cage. When three or more were singing at once an utter confusion of notes resulted, so that the rhythmical quality of their song was entirely obscured.

The song of the normal tree crickets in the other cage presented a striking contrast. Each individual sounded its notes in unison with the others as if a single cricket were singing.

The third insect tested was the Nebraska cone-head, *Neoconocephalus nebrascensis* Bruner, a member of the katydid family with slender green body and a head drawn out into a point in front. Its song consists of a continuous series of rasping, buzzing notes lasting a little over a second and separated by about equal intervals of silence. I have observed this species in the field synchronizing their notes at a distance of twenty paces between singers. Only four males were used in the experiment, two without front tibiae and two normal ones. On the second evening of the experiment the two earless cone-heads were singing with a very conspicuous lack of coordination. For about a minute their notes would sound alternately, then gradually one song would catch up with the other so that for another similar period the notes would sound simultaneously. At the same time the normal cone-heads were keeping up perfect synchronism. Sometimes one note could be heard to start a fraction of a second ahead of the other, but never once did I hear them entirely separated.

It might be argued that the insects without their front tibiae acted differently as the result of shock to their nervous systems received during the operation. This is extremely improbable, for the insects with bobbed front legs appeared to enjoy as excellent health as the normal ones and lived fully as long. Moreover, they never recovered in the slightest degree their ability to syn-

chronize. Among such insects the loss of a leg is a matter of small consequence. If they are held by the hind legs when captured they will often voluntarily kick off one or both in an effort to escape.

There is also a possibility, although a remote one, that the real hearing organs are concealed somewhere in the lower part of the tibiae or in the tarsus. Since these experiments localize the sense of hearing so near the tympanum or ear-drum with its bundles of sensory cells containing the so-called auditory pegs, there is little doubt but that sensory cells of this type are the organs responsible for hearing in insects.

We still leave unanswered the question of what range of sounds the crickets and katydids can hear. Do they merely hear the music of their own kind or do they hear many other sounds as well? This probably varies with each species, just as was found in the experiments with moths and caterpillars.

I regard as purely academic the question of whether sound waves arouse in insects the same sort of sensations that they do in man or whether the insects merely feel a tingling sensation as we might feel the vibrations of a violin string by touching it with a finger. The settlement of this question may have to wait until insects have evolved sufficiently in intelligence to have a written language and practice the indoor sport of introspection. The fact remains that insects can detect certain sound vibrations transmitted by the air and that they can react to them about as quickly as the higher animals do.

Granted that the crickets and katydids can hear their own kind, the reason why they sing to each other still remains shrouded in mystery. Why do some species maintain synchronized orchestras and others remain soloists? There is reason to believe that the primary utility of an insect's song is to call a mate, but their musical efforts seem to be carried to an excess not demanded by that purpose. In most cases the singing males seem to seek out the mute females. But the wing structures responsible for the music of insects were evolved eons ago under conditions about which we can hardly even guess. Nature goes to excess in most things. Possibly insect songs have no present utility at all, but the musical instruments have been retained, even perfected and specialized, because they were not harmful to the species possessing them.

WILL THE NEGRO SURVIVE IN THE NORTH?

By Professor S. J. HOLMES
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TEN years ago most students of the subject would have answered in the negative the question which forms the title of this article. Probably many of them would give the same answer today. But the vital statistics of the Negro have recently undergone such marked changes that the question is at least debatable, and if it should turn out that the affirmative answer is the correct one the matter is of grave concern for the racial composition of the American people, north as well as south.

The first decades after emancipation witnessed a rapid growth of our Negro population which afforded the occasion for widespread alarm. Between 1860 and 1880 the Negroes increased from 4,441,830 to 6,580,793, and by 1900 they numbered 8,833,994. This rather striking increase led several writers to express the fear that the country was on its way to becoming a second Haiti. However, the census returns of the last three decades showed that the Negro population, while continuing to grow, was increasing at a diminishing rate, and that the whites were multiplying much more rapidly than the Negroes. The fear of being swamped by the rising tide of black humanity has now mainly subsided, and some students of population problems have recently expressed the conviction that our colored inhabitants will soon be actually decreasing in numbers and that the race problem will ultimately solve itself. As far back as 1896 Dr. F. L. Hoffman made such a prediction in his well-known essay on "The Race Traits and Tendencies of the American Negro," and similar views were championed somewhat later by Dr. Corson in a fairly extensive survey of what he termed the vital equation of the Negro race. Both of these writers contended that the Negro was ill adapted to survive in competition with the white man. It was pointed out that the mortality of the Negro had been steadily increasing since the period of slavery. Suddenly freed from the surveillance of their white masters, the Negroes were forced to live under very unsanitary conditions and death became a frequent visitor to their squalid homes. Venereal diseases, tuberculosis and pneumonia ran riot; infant mortality was frightfully high, and although births came with unabated frequency, the vital prospects of the Negro seemed, on the whole, very unpromising. The conclusion appeared to be warranted that the Negro is a biologically unfit product who would be taken care of in due time through the drastic agency of natural selection.

This conclusion inevitably raises the question whether the high mortality of the Negro is due to his inherent physical inferiority or to the unfavorable conditions under which he lives. Undoubtedly hereditary racial factors influence the relative mortality of whites and blacks. There are several diseases to which Negroes are relatively unsusceptible. There are others, such as pneumonia and tuberculosis, to which the Negro falls a prey to an extent which can hardly be accounted for by his relatively unhygienic surroundings. The death-rate of the Negro population, however, has shown a marked decrease in the past three decades. So far as can be ascertained from our fragmentary data, Negro mortality reached a climax somewhere in the eighties. The mortal-

ity rates of the censuses of 1870, 1880 and 1890 are practically worthless, and we have to base our conclusions on the statistics of the few states and cities which kept adequate records during these periods. Taking the death-rates of the white and colored population in the registration area we find the following trend:

DEATH-RATES OF THE WHITE AND COLORED[1] POPULATION OF THE U. S. REGISTRATION AREA, 1890 TO 1920

	1890	1900	1910	1920
White	20.22	17.1	14.58	12.59
Colored	32.4	29.4	24.1	18.00

The Negro rate is still much the higher, but it is not so high as the white rate thirty years ago, and in many places it has declined at a more rapid pace.

Hygiene and public health measures are doing much to lengthen the average life of the Negro. The control of epidemics and the various means which medical science has discovered for the prevention and cure of disease have conferred their benefits on whites and blacks alike. Death-rates will decrease more slowly as the average duration of life approaches the natural limit of human longevity, and we can therefore look forward to a more rapid decrease of mortality in the Negroes than in the whites. The average duration of human life has been prolonged, not through an extension of its natural span, but by reducing the mortality of its early and middle periods. It is in these periods that the mortality of the white and black races differs most widely. It is in these periods also, and especially in early life, that death-rates are most readily affected by environmental causes. How closely the mortality of whites and blacks can be made to approach it is impossible to predict. Perhaps racial susceptibilities to certain diseases will continue to cause differences in mortality which no environmental changes will be able to eliminate. But, however this may be, it is unquestionable that great reductions in Negro mortality may be made before this limit is reached.

Since the mortality of the Negroes has undergone a marked reduction it is evident that their slackening rate of increase must be due largely to the decline in their birth-rate, although this decline has not been so rapid as in the whites. The excess of births over deaths has been lower among Negroes, but it has shown a tendency to approach the white rate in most of the states included in the registration area for births. In several northern states the Negroes have the higher birth-rate, but as a rule their mortality has been so high as to bring their net rate of increase below that of their white competitors. In the light of recent vital statistics, however, one can not be sure that this condition will last long.

It has been a commonly accepted conclusion that the Negro can not withstand the more rigorous climate of the northern states. There are few Negroes in the states bordering our northern boundary, and still fewer in Canada. Climate has been held to impose a barrier to the northward spread of the black man as it does to the distribution of many species of plants and animals. This conclusion has been supported by the fact that until very recently most northern states and cities have had more deaths than births in the Negro race.

Ever since the Civil War we have had an increasing migration of Negroes into the north. At first they did not, as a rule, travel far north, but of late they have been appearing in our northernmost states in rapidly increasing numbers. The demand for labor dur-

[1] The term "colored" as used in our vital statistics includes a few persons of other races besides the Negro, but in the regions considered the proportion of these is so small that no error of moment will be made by disregarding them.

ing the great war drew vast numbers into the industrial plants of our northern cities. Between 1910 and 1920 the Negro population of New York City was increased by 60,758, or 66.3 per cent.; that of Chicago by 65,355, or 148 per cent.; that of Cleveland by 26,003, or 307.8 per cent., and that of Detroit by 35,097, or 611.3 per cent. Since the war, Negro migration slackened, but it still continues to a large but not precisely ascertainable extent. The shortage of labor arising from the restriction of European immigration has created, and will continue to create, a demand for Negro employees which will cause a steady inpouring of black humanity into our northern centers of industry. The Negro bids fair to supply no small part of our laboring population in many kinds of employment. He finds conditions in the north more attractive in several respects than in the south. He usually secures better wages, a superior social status and better educational advantages for his children. Often he has to put up with housing conditions of the worst description, but they are, as a rule, no worse than those he left behind. But his conditions of life in the north are improving. With improved facilities for education, combined with higher wages, his station in life may become quite as favorable as that of the whites in similar employments.

But will he thrive? Formerly the Negro armies have been marching north to their destruction. A study of the balance sheet of births and deaths in any of the states or cities of the north shows that deaths among the Negroes have everywhere been more numerous than births. Pneumonia, tuberculosis, venereal diseases, a high infant mortality and the various ailments resulting from ignorance and improvidence have taken so heavy a toll that even Negro fecundity was unable to compensate for the losses. Recently, however, the situation has begun to take on a new aspect. In several northern states and cities Negro births have become more frequent than Negro deaths. The last two volumes on birth statistics (1924, 1925) show more births than deaths in California, Connecticut, Illinois, Indiana, Maryland, Massachusetts, Michigan, Montana, Nebraska, New Hampshire, New Jersey, New York, North Dakota, Ohio, Oregon, Pennsylvania, Rhode Island, Utah and Washington, whereas in 1915 all these states in the registration area which had any considerable number of Negroes showed, with the exception of Massachusetts, an excess of deaths over births. One has to allow something, of course, for improvements in the registration of births, but the fact that these states are in the registration area indicates that their records had reached a fairly high standard.

Another factor which should be considered is the age composition of the Negro population. Recent migrants to the north include many Negroes in the middle period of life when child-bearing is relatively frequent, and our statistics might therefore give an exaggerated picture of the real fecundity of the group. Fortunately a certain amount of check is supplied by the data which the Bureau of the Census has recently published on the size of families. These data show that in practically all the northern states the total number of children born to each mother who gave birth to a child during the year is greater in the colored than in the native white population, although somewhat less than the number of children of mothers who were foreign born. When we allow for mortality by considering only living children the advantage still lies with the colored family as compared with that of the native-born whites. The same relation is shown when we measure the birth-rate by taking the number of births per thousand women of child-bearing age. The available data agree in pointing to the conclusion that the

AVERAGE NUMBER OF CHILDREN EVER BORN TO WOMEN WHO BECAME MOTHERS IN 1924 BY COLOR AND NATIVITY IN REPRESENTATIVE NORTHERN STATES

	Native Born	Foreign Born	Colored
Registration area	3.0	3.9	3.7
Cities	2.5	3.6	3.1
Rural districts	3.4	4.7	4.0
California	2.4	3.4	3.2
Connecticut	2.6	4.2	3.3
Illinois	2.7	3.6	3.0
Indiana	3.1	4.0	3.4
Iowa	3.0	4.1	3.1
Kansas	3.1	4.6	3.4
Maryland	3.2	4.2	4.0
Michigan	3.0	3.8	3.2
Minnesota	3.1	4.4	3.6
New York	2.6	3.5	2.9
Ohio	2.9	4.0	3.3
Pennsylvania	3.1	4.8	3.2

Negroes are more than holding their own in most places in the north. Up to the period of the great epidemic of influenza the balance sheet of births and deaths was against the northern Negro; during the last four or five years it has been decidedly in his favor.

Northern Negroes are largely inhabitants of cities. The efficient means taken in many northern cities for the promotion of public health have materially increased the Negro's chances of survival. In New York City, whose public health administration is one of the best and whose Negro population is now one of the largest (over 160,000), the death-rate of the Negroes has markedly decreased, while the birth-rate has been rising. The previously very high infant mortality of the Negroes has declined more rapidly than that of the whites. In fact, *it has been nearly cut in half in the short space of a single decade,* and is now at a point lower than the rate for white infants not many years ago. With an improved milk supply, free clinics, opportunities for prenatal care and various other means for promoting the welfare of mother and child, the Negroes of New York City are finding conditions quite favorable for the perpetuation of their kind. The large life insurance companies, such as the Metropolitan, have done much through health education and supplying free nurses to increase the longevity of their colored patrons. The treatment of expectant mothers afflicted with syphilis, which is so common a scourge of the American Negro, has proven effective in the reduction of still-births and abortions, and will doubtless tend to enhance the birth-rate and reduce infant mortality. It is not surprising that New York City was among the first of the cities of the north to show a preponderance of births over deaths in its Negro population.

In connection with the problem of the fate of the northern Negro it is of interest to compare the vital statistics of Negroes in northern and in southern cities. Taking the cities of the northern states in the registration area for births in 1924, we find a surplus of 11,729 births over deaths, whereas in the cities of the six states in this area south of the Ohio and Potomac rivers the excess of births over deaths is only 227. It is true that the northern cities contain a larger number of Negro inhabitants, but less than three times as many (1,603,021 as compared with 644,309), while if we consider their excess of births over deaths they have contributed more than fifty times as many persons to the Negro population. In the cities of South Carolina, Mississippi and Kentucky there were actually more Negro deaths than births.

INFANT MORTALITY RATES (DEATHS PER ONE THOUSAND BIRTHS) OF THE WHITE AND COLORED POPULATION OF NEW YORK CITY, 1915–1924

	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924
White	97	92	87	90	79	83	69	73	65	66
Colored	200	169	176	171	145	157	135	117	116	106

If we are not to be misled by the trickiness of vital statistics in interpreting the meaning of these striking facts we must be on our guard against various sources of error. Aside from the incompleteness of registration, especially of births, which is apt to be greater among the Negroes than the whites, there are differences in age composition to which we have referred which have a marked influence on crude birth and death rates. But when urban mortality rates are adjusted for age there is, in general, a higher Negro mortality in southern than in northern cities, indicating that conditions of life are more favorable for the urban Negro in the northern states. For reasons previously given, the increase of the Negro birth-rate in northern cities probably represents a real condition instead of a mere statistical relation. It required some time for the numerous migrants of the war period to become more or less established. The rise of the Negro birth-rate in the north probably reflects the influence of an improving economic status and a better adjustment to a new environment. While it may be too soon to assert that the northern Negroes will continue to increase through their own birth-rate, the conclusion that they can not survive in a higher latitude is hardly warranted by existing facts.

Cityward migration checks the multiplication of blacks as well as whites, but it may well happen that the improvement of our public-health activities will bring about a still greater preponderance of Negro births over deaths in the northern states. Possibly the Negro is destined to form the relatively fecund stratum of our urban population which supplies a large share of our unskilled and partly skilled labor. By nature the Negro is endowed with a physical constitution which is probably not inferior to that of his white compatriot. Although his racial heredity may predispose him to tuberculosis and pneumonia, there is evidence that he is building up a partial immunity to these diseases similar to that acquired by the whites. If he proves successful in adapting himself to these maladies his high mortality may become a temporary episode of his history which may be overcome through education and improved economic conditions. If the Negro is destined to decrease in numbers it will be owing, I believe, more to causes affecting the birth-rate than to any physical inferiority which makes for high mortality.

Other things equal, a low-standard population tends to outbreed a high-standard population. If the north proves to be a field in which the Negro race is capable of expansion through its own birth-rate there is no way to predict the extent of its eventual spread. Hitherto the whites have increased much more rapidly than the Negroes, but we should remember that up to the period of the great war we were receiving annually a large army of immigrants from Europe, and that these immigrants were a very prolific group. The second generation of immigrants, although less prolific than their parents, continued to produce larger families than the native-born Americans of native parentage. Over large areas, especially in the north and east, this latter group has probably not been self-perpetuating. With the drastic restriction of European immigration we may expect a further fall in the birth-rate of the northern whites. Had it not been for our immigrants and their immediate descendants the rate of increase of our white population would have approached much more closely to that of the Negroes. Perhaps the future will see a larger proportion of Negroes in the north than in the south. No one knows. There are too many uncertain factors in the problem to make prediction safe, but the next few years will probably bring us data for making a much better judgment than is possible at the present time.

EXPERIMENTAL DETERMINATION OF THE VELOCITY OF LIGHT[1]

By ALBERT A. MICHELSON, U. S. N.

CONSIDERING the importance of this physical constant as one of the simplest and most accurate means of ascertaining the distance of the sun from the earth, it seems surprising that but three scientists have sought to obtain it experimentally.

These were Foucault, Fizeau and more recently Cornu.

Foucault used the method known as that of "Wheatstone's revolving mirror," the application of which was first suggested by Arago.

Fizeau and Cornu both used another method, known as that of the "toothed wheel."

In Foucault's experiments the distance traversed by the light was 20 meters. The result obtained was 185,200 miles per second. Cornu's stations were about 14 miles apart. The result obtained by him was 186,600 miles, which exceeds the former one by 1,400 miles.

The objection to Foucault's method is that the displacement, a quantity which enters directly in the formula, is very small, and therefore difficult to measure accurately. The objection to Fizeau's is that the time of total disappearance of the light was necessarily uncertain.

The object of the experiments which I have undertaken is to increase the displacement in the first method. This can be done in several ways: 1st, by increasing the speed of the mirror; 2nd, by increasing the distance between the two mirrors; 3rd, by increasing the radius of measurement, *i.e.*, the distance from the revolving mirror to the scale.

In Foucault's experiments the speed of the mirror was 400 turns per second: the radius of measurement was about one mètre, and the distance between the mirrors was about ten (10) mètres. The displacement obtained was about 0·8 milimètre.

In my experiments, the speed of the mirror was but 130 turns per second—but the radius of measurement was from fifteen to thirty feet—and the distance between the mirrors was about 500 feet.

The displacement obtained varied from 0·3 inch, to 0·63 inch, or about twenty times that obtained by Foucault.

With a greater distance between the mirrors, and better apparatus, I expect to obtain a displacement of two or three inches and to measure it to within one thousandth part of an inch.

The following is a description of the apparatus employed in these preliminary experiments.

Fig. 1 represents the plan. The sun's rays are reflected by a heliostat through a slit *S*, and upon a mirror *R*, which revolves about a vertical diameter. They are thence reflected to a fixed plane mirror *M*, upon the surface of which an image of the slit is formed by means of the lens *L*. The light now retraces its path, and finally forms an image of the slit, which, when the mirror, *R*, is at rest, coincides exactly with the slit itself. When the mirror revolves slowly, this coincidence is still maintained, but the

[1] Reproduced on the occasion of the fiftieth anniversary of the presentation of this historical paper before the American Association for the Advancement of Science. It was printed in 1878 in the *Proceedings* of the Association. The Michelson Meeting of the Optical Society which convened during the first week of November celebrated this event. An account of this meeting—together with a picture of Dr. Michelson—may be found at the end of this number.

image is perceived by flashes of light at each revolution till they follow each other in such rapid succession as to form a continuous impression. This image is displaced more and more as the revolution becomes more rapid, the displacement being twice as great as the displacement of the mirror, during the time required for the light to travel from *R* to *M* and back again.

It will be observed that the difference between this arrangement and that of Foucault is that the concave mirror is dispensed with, its office being accomplished by the lens and plane mirror; and that this arrangement permits the use of *any* distance between the mirrors.

When the revolving mirror is in the astronomical focus of the lens, the light, reflected from it in directions continually changing as the mirror revolves,

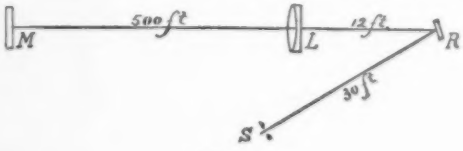


FIG. 1

is, after passing through the lens, always rendered parallel to the axis. Thus, all the light which comes during the part of a revolution represented by the angle subtended by the lens, is collected into a succession of pencils whose axes remain parallel to the axis of the lens; hence the distance between the mirrors may be as great as we please.

It is to be remarked, however, that as this distance is increased, the radius (or distance *R S*, Fig. 1) must be decreased, if we wish to preserve the maximum of light. In practice, it was found unnecessary to place the revolving mirror at the astronomical focus of the lens, and, in fact, this distance was in some cases only one fourth the focal length of the lens.

Other things equal, the greater the diameter and the focal length of the lens, the brighter will be the image.

In these experiments the lens and the fixed mirror were those used in one of the expeditions for observing the transit of Venus. The lens was five inches in diameter and thirty-nine feet focal length. The mirror was tested and found to be almost exactly plane. For these experiments it had to be silvered on the front surface.

The lens being in position, the mirror, which had a slow motion in two planes, was adjusted perpendicular to the line passing through their centres, as follows:

A rough adjustment was made by sighting along a square applied to the mirror, and then an observer, with a telescope placed behind the centre of the lens, saw, reflected in the distant mirror, the image of some adjacent object. By signals the mirror was moved till the observer saw the reflection of his telescope exactly in the centre of the mirror, when the adjustment was complete. This adjustment had to be repeated from day to day.

The revolving mirror was next brought into position, and then the slit placed so as to allow the beam of light passing through it to fall on the revolving mirror, and at such a distance that the image of the slit was superposed upon the slit itself.

The revolving mirror was a disc of plane glass about one inch in diameter—silvered on one side, and supported by two screws, terminating in needle points, which fitted into two small conical holes in the edge of the disc.

It was driven round by a blast of air from a bellows, which impinged upon one half of the mirror. *t*, *t*, *t*, Fig. 2, represents a section of the tube supplying the air. *R*, *R*, is a section of the glass disc; and *O*, is the axis about which it turns.

This crude piece of apparatus is now supplanted by a turbine wheel, which

insures a steadier and more uniform motion.

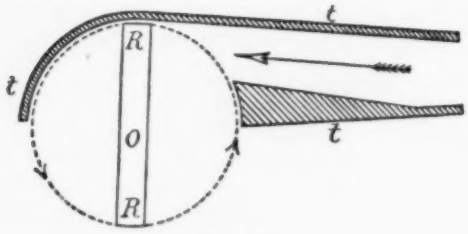


FIG. 2

For keeping the speed constant and for measuring it accurately two devices were used. In the first the light reflected from the revolving mirror fell upon the toothed wheel of a chronograph, which itself was accurately timed after each experiment.

When the time between the passage of two adjacent teeth was the same as the time of one revolution of the mirror, then the wheel appeared stationary, turning slowly forwards or backwards as the mirror revolved too slowly or too rapidly.

In the latter part of the experiments, a tuning-fork, bearing a mirror on one prong, was used. This was kept in vibration by a current of electricity. The fork was placed so that an observer, about to measure the displacement, could also see, in the mirror attached to the fork, an image of the revolving mirror. When both mirrors are at rest, this image is of course similar to the object; but when the fork is set in vibration the image is drawn out into a band.

When, however, the revolving mirror is started and attains the proper speed, the image again assumes its original shape. The fork is afterwards compared with one of König's standards.

The slit and micrometer were connected so as to form but one piece. This piece of apparatus is represented in Fig. 3. *S*, is the slit; *ab*, a piece of plane glass partly silvered. The light, proceeding in the direction *SM*, is reflected in the contrary direction, and part of it is reflected from the glass *ab*, forming an image of the slit which is made to coincide with the cross-hairs at *d*. When the mirror revolves this image is displaced to *d'*. The slit *S* may then be moved in the direction *SS'* till the *displaced* image coincides with the cross-hairs, and the distance *SS'* accurately read by a screw bearing a divided circle. This method of observing does away with any error which might arise from "parallax" due to inexact focusing.

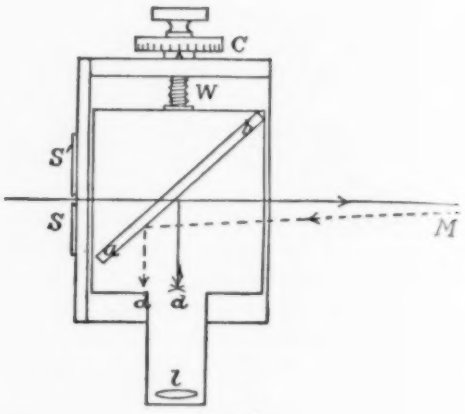


FIG. 3

In these experiments the displacement was so great that the slit moved entirely outside the field of light. To avoid this difficulty, the other parts of the apparatus, viz.: *ab*, the glass mirror, *d*, the cross-hairs, and *l*, the lens for viewing the image—were moved by the screw *w* in the opposite direction past the slit; the distance moved, which is exactly equal to the displacement, is accurately read on the divided circle *c*.

The piece of glass *ab* was partly silvered in order that when the mirror was at rest, the image of the slit would be seen from the unsilvered portion, while the *displaced* image, which is very much fainter, would be seen by reflection from the silvered part.

The annexed table gives the results of ten independent observations, made under difficulties and with apparatus adapted from the material found in the Laboratory of the Naval School:

Their accordance with each other and with the generally accepted result justifies the expectation of obtaining, with proper appliances and under more favorable conditions, the correct result within a few miles; and, I trust, justifies the demand I have made on your time and attention.

In conclusion, I take this opportunity of tendering thanks to Mr. A. G. Heminway, of New York, for contributing $2,000 for the purpose of carrying out these experiments.

RESULTS OF OBSERVATIONS

Velocity of Light in Air in Miles Per Second
186,730
188,820
186,330
185,330
187,900
184,500
185,000
186,770
185,800
187,900
Mean – 186,508

Formula, $V = \frac{4 \pi r n D}{\delta}$

V = velocity of light.
r = radius of measurement.
n = number turns per sec.
D = twice dist. bet. mirrors.
δ = displacement.

ALBERT A. MICHELSON

THE PROGRESS OF SCIENCE

THE MICHELSON MEETING OF THE OPTICAL SOCIETY OF AMERICA

By Hugh G. Boutell

Probably the most notable and interesting meeting which has ever taken place in the lecture room of the National Bureau of Standards was that of the Optical Society of America on the afternoon of November 2, when members of the society, a large percentage of the staff of the Bureau, and as many others as could possibly get within the hall or around the loud-speakers outside gathered to hear Professor Albert A. Michelson present the results of his latest experiment on ether drift, and incidentally to do honor to the dean of American optics. If Professor Michelson experienced any disappointment in getting no indication of ether drift in his latest repetition of the Michelson-Morley experiment it must have been more than offset by the reception which was given him at the "Michelson Meeting" of the Optical Society.

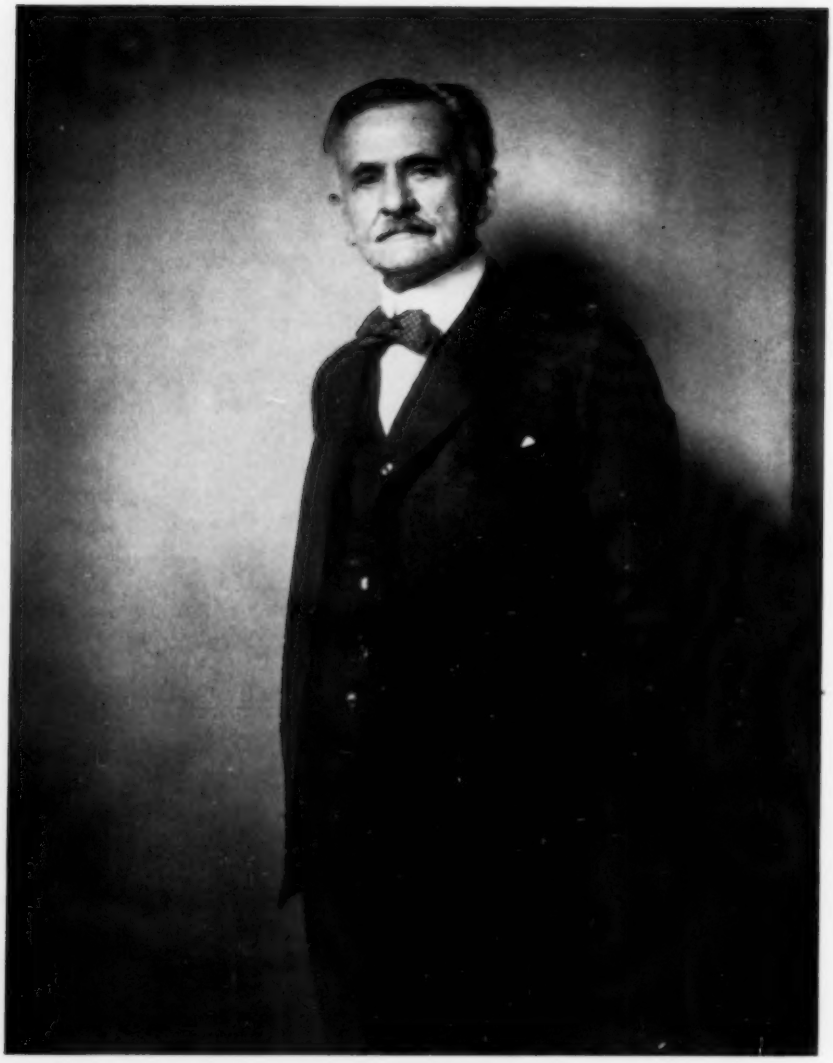
It was peculiarly fitting that when the executive council was planning this thirteenth annual meeting of the society, they should decide to name it "the Michelson Meeting," because it was just 50 years ago that A. A. Michelson, then an ensign at the United States Naval Academy, now the veteran of many victories in the intellectual conquest of nature, published his first contribution to a scientific journal, an item of only a few lines and a single diagram on his now renowned method for measuring the velocity of light (*Silliman's Journal*, Vol. 15, p. 394; May, 1878). The method was described in detail in a paper presented at the meeting of the American Association for the Advancement of Science in August, 1878, which is reprinted from the *Proceedings* in the present issue of The Scientific Monthly.

As Mr. I. G. Priest, the president of the Optical Society, said, it is human custom to celebrate various occasions, birthdays and even deaths; but the Optical Society had chosen this occasion to celebrate the intellectual birthday when the man Michelson was born into the field of work in which he is now the acknowledged leader.

This semi-centennial was distinguished above all else by the happy fact that, after half a century of devotion to research in optics, Professor Michelson himself contributed the outstanding paper on the program—"Results of Repetition of the Michelson-Morley Experiment." After he had narrated briefly the history of this famous experiment, and described his new apparatus, he announced that his recent experiments, in collaboration with Messrs. Pease and Pearson, showed no difference in the velocity of light in various directions of as much as 1/500 of that which should be found if the earth really is drifting through a stationary ether. His latest experiment therefore confirms the results of his first attempt to measure the absolute motion of the earth through space in 1887.

Following Professor Michelson's paper, tributes of appreciation and respect were paid to this indefatigable investigator by Professors Lyman, Swann, Richtmyer and Miller.

On the same evening a dinner in honor of Professor Michelson was held at the Cosmos Club. Among the speakers was Dr. C. E. Munroe, of the National Research Council, internationally known authority on explosives, and an intimate friend of Professor Michelson at Annapolis. His references to Professor Michelson's early work and particularly to his many activities and interests out-



Very sincerely yours
A. A. Michelson

—Courtesy of the Optical Society of America

side the field of physics, were of the greatest interest. Dr. Munroe took this occasion to return to Professor Michelson an oil painting of a plate of apples which the latter had executed when he was considering the possibility of supplementing his skill by a knowledge of painting. The picture was a creditable performance and Dr. Munroe suggested that it be used as the nucleus of a permanent collection of material associated with Professor Michelson's early work.

Professor Michelson's address at this dinner was also rich in reminiscences of his younger days, among them being the time when one of the instructors at the Naval Academy took him to task for his lack of interest in subjects other than mathematics, chemistry and physics and warned him to drop this "scientific stuff." He attributed his interest in what later became his life's work to an assignment by Admiral Sampson to deliver a lecture on the velocity of light. It was while developing an apparatus to be used for demonstration purposes in this lecture that he started to make actual measurements of the speed of light on his own account.

The dinner was likewise notable as the occasion selected by Dr. Herbert E. Ives for presentation to the Optical Society of America of the Frederic Ives medal which Dr. Ives has endowed in honor of his father, distinguished for his pioneer contributions to color photography, photoengraving, three-color process printing and other branches of applied optics. The medal will be awarded biennially by the society "for distinguished work in optics."

Thirty-nine papers were presented on many diverse subjects in optics. An unusual feature was the presentation, for the first time in the United States, of the remarkable motion picture film made by Professor W. H. Wright at the Lick Observatory, illustrating the rotation of the planet Jupiter. Not only was every surface feature presented on the screen, as the great sphere turned on its axis, but a transit of one of the satellites and its shadow was visible as light and dark spots crossing the disk. Pictures in ultra-violet and infra-red light gave very different aspects, showing the greater penetration of the red light through the planet's atmosphere.

Another feature which excited great interest and admiration was the demonstration of Technicolor motion pictures by Dr. L. T. Troland.

In connection with the meeting an extensive exhibit of optical instruments and related material was arranged by a special committee of the society and the Bureau of Standards. The latest designs of optical equipment were shown by prominent manufacturers in this field.

The development of the microscope from 1665 to recent times was shown in a special exhibit of original instruments and reproductions kindly loaned for the occasion by the Medical Museum of the United States Army.

An interesting collection of ancient and modern books on optics (including most of those containing Professor Michelson's contributions), photographs and engravings was shown by the Smithsonian Division of the Library of Congress.

The book registration for the meeting was about 675 and it is estimated that probably one thousand persons visited the exhibition or attended some session of the meeting. About 400 persons heard Professor Michelson's paper and probably as many more were turned away from the overcrowded lecture hall. Over 200 persons attended the dinner, and more would have come had there been places for them. In order to satisfy the demands of those who wished to see the motion pictures of the planet and the Technicolor motion pictures, these were all shown three times and were seen by about one thousand persons.

THE MICHELSON-MORLEY ETHER DRIFT EXPERIMENT

When Professor A. A. Michelson, of the University of Chicago, announced at the meeting of the American Optical Society the latest results of his work on ether drift, he wrote the latest chapter in a history which he began, and in which the theory of relativity that made famous the name of Einstein plays an important part.

According to a review of the work prepared by *Science Service* it was in 1887 that Professor Michelson, then at the Case School of Applied Science in Cleveland, collaborated with his colleague, Professor E. W. Morley, in performing the now classical Michelson-Morley experiment. Up to that time scientists were generally agreed in supposing that light waves traveled through a queer medium which pervaded all space, and which was called the ether. If the ether was in all space, then it should be possible to detect the earth's motion through it. The earth travels around in its orbit at a speed of about 20 miles per second. If a beam of light is divided into two parts then sent in directions at right angles to each other, reflected from two mirrors back and recombined, light and dark bands may appear. These are due to the light waves getting tangled up, and interfering, and so are called interference bands.

If one beam of light has to travel a little longer than the other, the bands are moved and so the method affords a very delicate method of measuring minute displacements. In one form this interferometer has proved a valuable scientific measuring instrument. Motion through an ether would produce the same effect as a lengthening of one of the beams, and so would theoretically cause a shift in the fringes, depending on the direction of the light paths with respect to the earth's motion. Professor Michelson and Professor Morley tried the experiment, but found an effect far less than that expected. So small was it that they attributed it to unavoidable errors. Other experiments were later devised to show the same effect, but none of them gave any evidence of the earth's drifting through the ether.

Then physicists began to search around for some explanation of why this effect did not occur. Professor H. A. Lorentz, of Holland, proposed what is now termed the Lorentz-Fitzgerald contraction. This was that motion through space produces an actual shrinkage of physical objects, which would just balance the effect sought for. As all measuring sticks would be similarly affected, it would be impossible to detect this contraction. Finally, as a further development of these ideas, Einstein proposed his preliminary theory of relativity in 1905, followed by his general theory in 1915.

In the ten years after the publication of Einstein's paper, the three "proofs" of the theory that he suggested were all successful. One was the explanation of the strange behavior of the orbit of the planet Mercury. Another was the bending of light waves as they passed near the sun, shown by observations made during solar eclipses. The third was the shift in the lines of the sun's spectrum when compared with spectra of light from terrestrial sources. Accordingly, the relativity theory was placed on just about as firm a foundation as a theory could be.

But a difficulty appeared in 1925. Dr. Dayton C. Miller, professor of physics at the Case School of Applied Science, where Michelson had first performed his experiment, tried it again. Miller obtained small effects, less than had originally been expected, but apparently definite and consistent. They seemed to show a motion of the earth towards part of the sky near the constellation of Lyra. As astronomers actually

recognize the existence of such a motion, the results seemed rather convincing.

Though efforts were made at the time to get Professor Michelson to comment on this result, surprising to science because it did show an effect, he said nothing. However, he was not satisfied with the situation so he set out to repeat the experiment himself. In the meantime other scientists tried the experiment, one in Germany even making observations from a balloon, but none confirmed Professor Miller's results. All gave the same negative result that had been obtained before.

No one questioned the accuracy of the original Michelson-Morley experiment. Professor Miller pointed out that Michelson had obtained a slight effect, attributed to experimental errors, and that it was genuine. Still Professor Michelson said nothing, but continued his preparations to repeat the experiment on a far more accurate scale than ever before. If he still obtained the small effect, it would be obvious that it was real, but if it were eliminated or greatly reduced, then it would be apparent that in originally attributing it to experimental errors he had been justified.

The apparatus was set up in one of the buildings of the Mt. Wilson Observatory in Pasadena, California. The steel plate on which the 100-inch mirror of the observatory's great reflecting telescope had been ground was used to support the apparatus. In his experiment originally, and as repeated by Miller, the observer had to walk around it as it turned, at the same time making the observations. The new apparatus was so arranged that the observer made his observations from the room above through an eyepiece directly above the center of the instrument. Though forced to spend several sojourns in hospitals, Professor Michelson was assisted by two members of the observatory staff, Francis G. Pease and Fred Pearson, and the work was carried out. Last September he went to Pasadena to make the final series of observations.

Now he has announced his results. With the motion of the earth of approximately 20 miles per second, the theoretical displacement due to drift through the ether should be about equal to one half the width of the bands. "I found no shift as large as a thousandth of the width of a band," Professor Michelson said.

As the very slight observed shift is about a tenth of what he got in 1887, it now seems certain that it is due to experimental errors, and that the larger effect obtained by Professor Miller was due to some other cause. Just what this cause was, he does not suggest, and neither does Professor Miller.

THE NEW YORK MEETING OF THE AMERICAN ASSOCIATION

THE American Association for the Advancement of Science and the Associated Scientific Societies will meet in New York City from December 27 to January 2. It is one of the greater convocation week meetings held at intervals of four years successively in Washington, New York and Chicago. The twelve years since the association last met in New York have been a significant period in the history of the nation and in the progress of science, and we may expect the approaching meeting to exceed all others in the work that it will accomplish for the advancement of research and the wider diffusion of scientific interest.

Dr. Henry Fairfield Osborn, president of the association, will be able to welcome it to the American Museum of Natural History, which under his direction has become one of the great scientific institutions of the world. The meetings of the association, of its fifteen

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sections, and of the forty-four associated societies will be held mainly at Columbia University and at the American Museum, but some sixty scientific and educational institutions of the city are cooperating in the arrangements.

The opening meeting will be on Thursday evening in the American Museum, when, after brief addresses of welcome Professor Charles P. Berkey, of Columbia University, will speak on recent researches on the geology of Mongolia. There will follow a general reception and the exhibition halls of the museum will be open, several new exhibits being on view for the first time.

On Monday evening Professor A. A. Noyes, of the California Institute of Technology, retiring president of the association, will give the annual address on "The Story of the Elements." Among evening addresses in the museum will be the Sigma Xi lecture by Professor Arthur H. Compton, of the University of Chicago, recently awarded one of the Nobel Prizes, whose subject is "What is Light?" Professor W. M. Wheeler, of Harvard University, will lecture on new tendencies in biological theory. Professor Harlow Shapley, director of the Harvard College Observatory, will speak on "Galaxies of Galaxies." After each of these addresses there will be a reception and the corresponding halls of the museum will be open throughout the evening.

Among the large number of general addresses may be noted the Josiah Willard Gibbs lecture by Professor G. H. Hardy, of the University of Oxford, entitled "An Introduction to the Theory of Numbers"; one by Professor Franz Boas, of Columbia University, on "Immigration of Asiatic Races and Cultures to North America," and the exhibition of a Canti film showing in motion pictures the behavior of tissue cells, by Professor Charles A. Kofoid, of the University of California.

Each of the sections and societies meeting during the week has its own program which in many cases includes general addresses, joint meetings and symposia that are of interest to those

—From the American Museum of Natural History

THE AMERICAN MUSEUM OF NATURAL HISTORY

who are not specialists. A list of these would fill an entire issue of this magazine; the full program will extend to three hundred pages.

The groups of scientific men will have their dinners, smokers and other social events. The scientific exhibit gives not only an opportunity to learn about recent advances, but also provides a place where scientific men can meet one another. This year there is an intervening Sunday which gives opportunity for a philharmonic symphony concert in Carnegie Hall, a reception at the Metropolitan Museum of Art, and day excursions to the New York Botanical Garden, the Aquarium, the Medical Center of Columbia University and the Presbyterian Hospital, the Cornell University Medical College, the Rockefeller Institute for Medical Research, the Boyce Thompson Institute for Plant Research and other scientific and educational institutions.

—From the American Museum of Natural History

THE MORGAN HALL OF GEMS, AMERICAN MUSEUM OF NATURAL HISTORY

THE NEW PHYSICS-BUILDING OF COLUMBIA UNIVERSITY

The local arrangements for the meeting are in the hands of an executive committee, of which Professor George B. Pegram, dean of the School of Applied Science of Columbia University, is chairman, Professor M. I. Pupin, president of the association four years ago, honorary chairman, and Professor Sam F. Trelease, secretary. There are numerous special committees on which the scientific men and the scientific institutions of the city are fully represented. The association is especially fortunate in the circumstance that Professor Osborn, its president, has been able to take a leading part in the arrangements.

The issue of *Science* for November 30 contains the preliminary program, edited by Professor Burton E. Livingston, with full details concerning hotel headquarters, transportation, places of meeting and the more general features of the program. A copy of this issue of *Science* can be obtained without charge from the Permanent Secretary of the American Association for the Advancement of Science, Smithsonian Institution Building, Washington, D. C.

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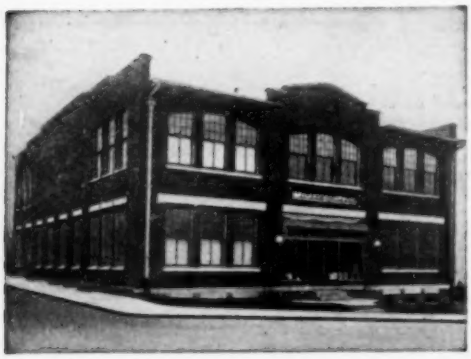

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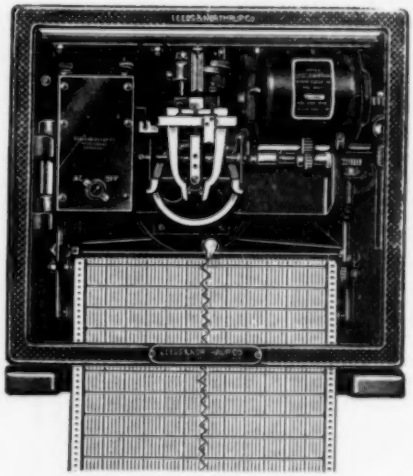

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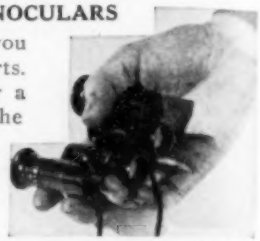

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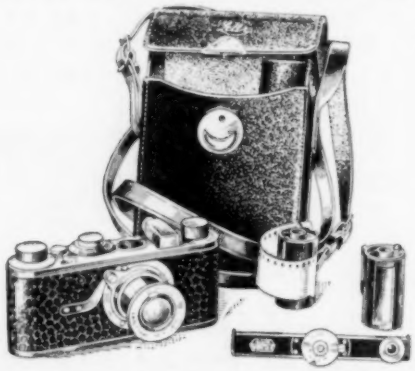

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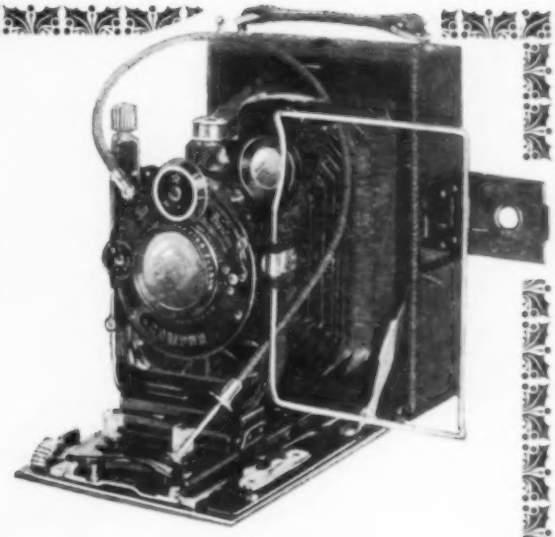

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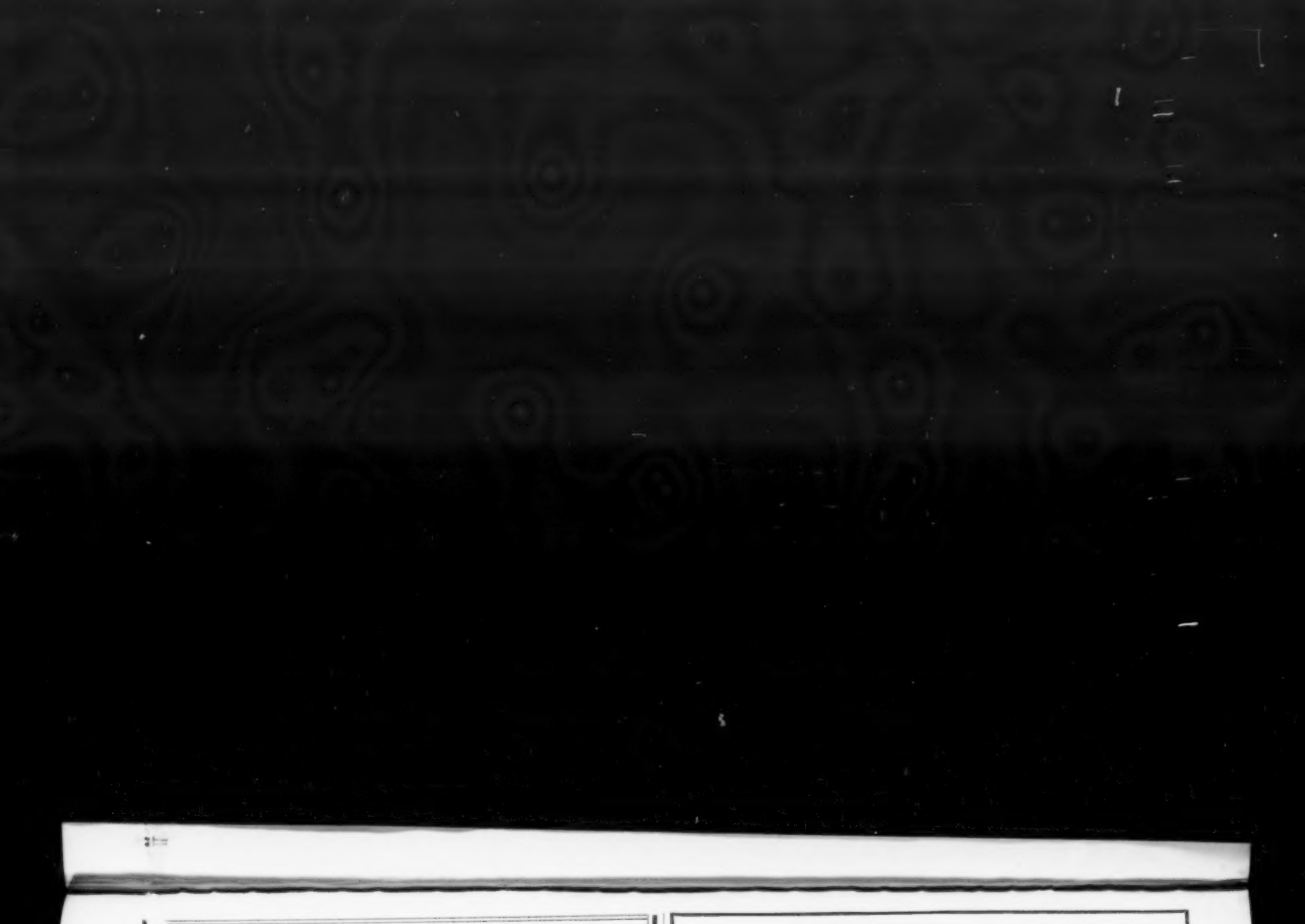
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